NASA's New Horizons Mission to Pluto and Beyond

Dr. Henry Throop
New Horizons Science Team

Senior Scientist
Planetary Science Institute
Tucson, Arizona / Mumbai, India

Astronomy Winter School
Hyderabad, 21 Feb 2017

This is a Galaxy. It has 100,000,000,000 stars.

The Sun is just one star in the Galaxy.

Our Solar System

Kuiper Belt

Jupiter

Mercury, Venus, Earth, Mars

Sun

Saturn

Uranus

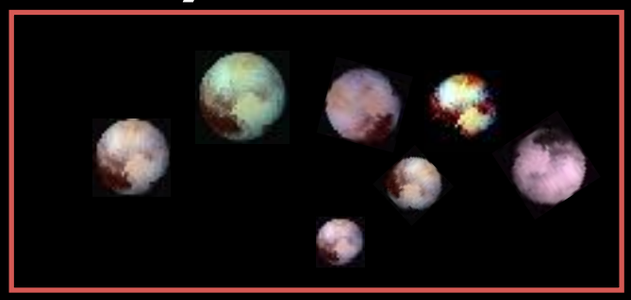
Neptune

Pluto

Rocky Planets

Gas Giant Planets

Icy Planets

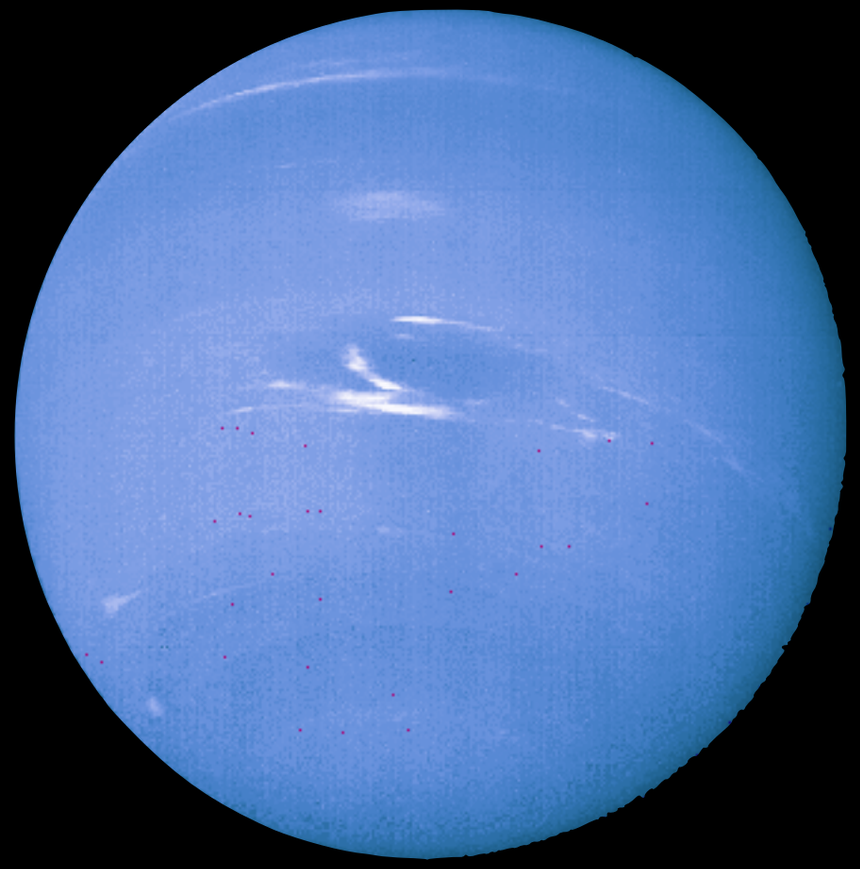


Easy to see:

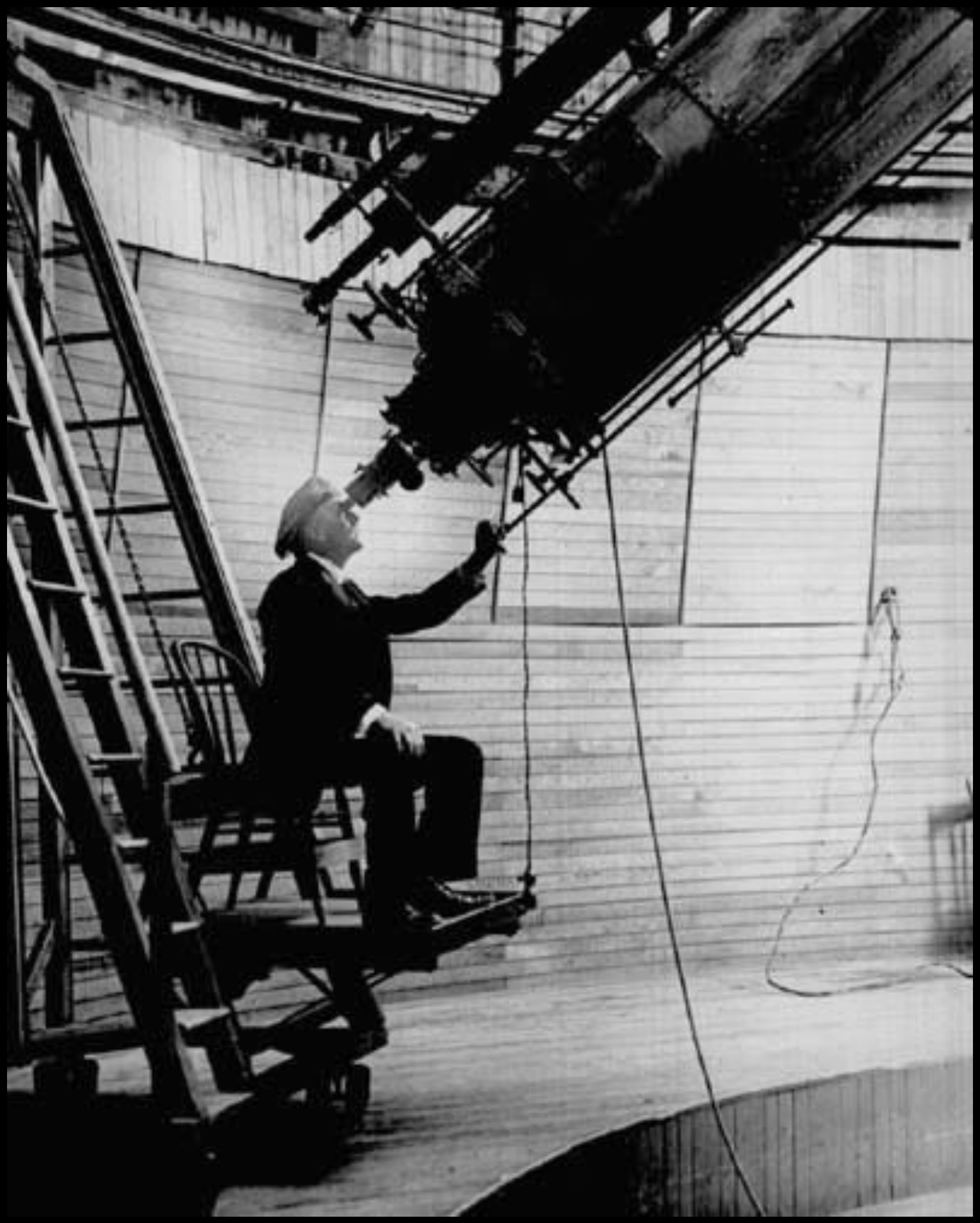
Sun
Moon
Venus
Mercury
Earth
Mars
Jupiter
Saturn

Hard to see:

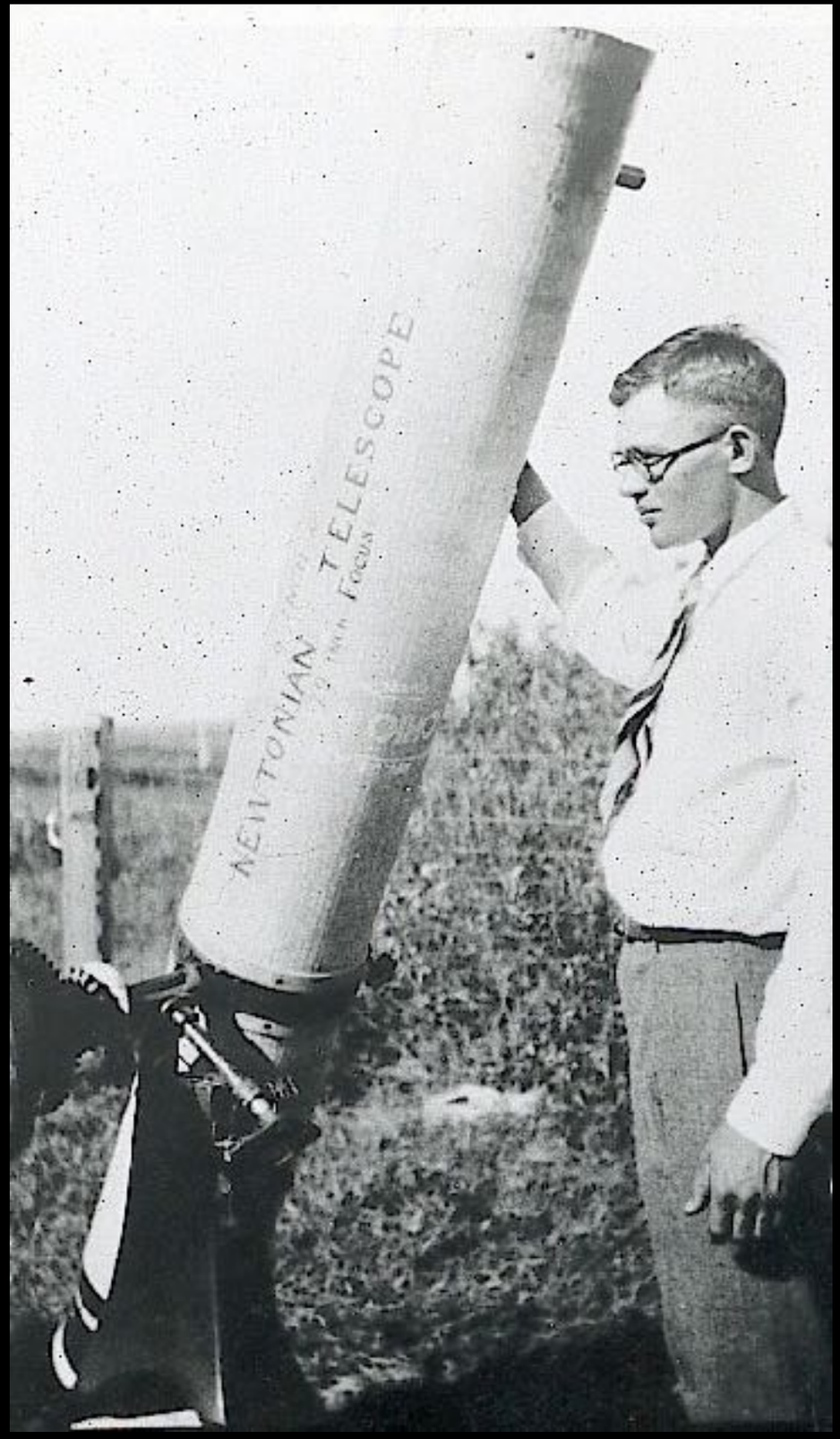
Uranus
Neptune
Pluto
Asteroids



1874: French astronomer Urbain Le Verrier found errors in the position of Uranus, and discovered Neptune exactly where he predicted it.

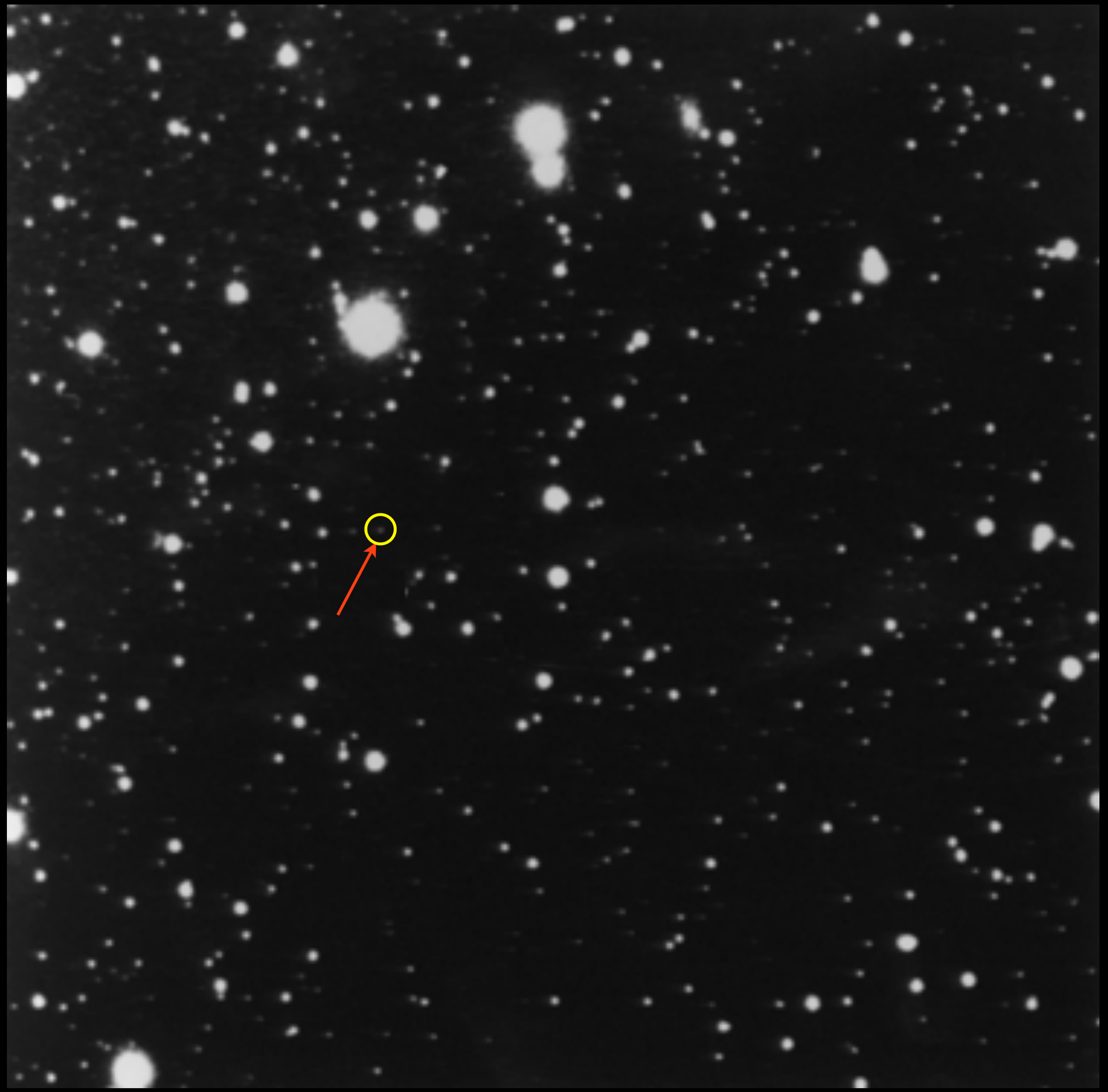


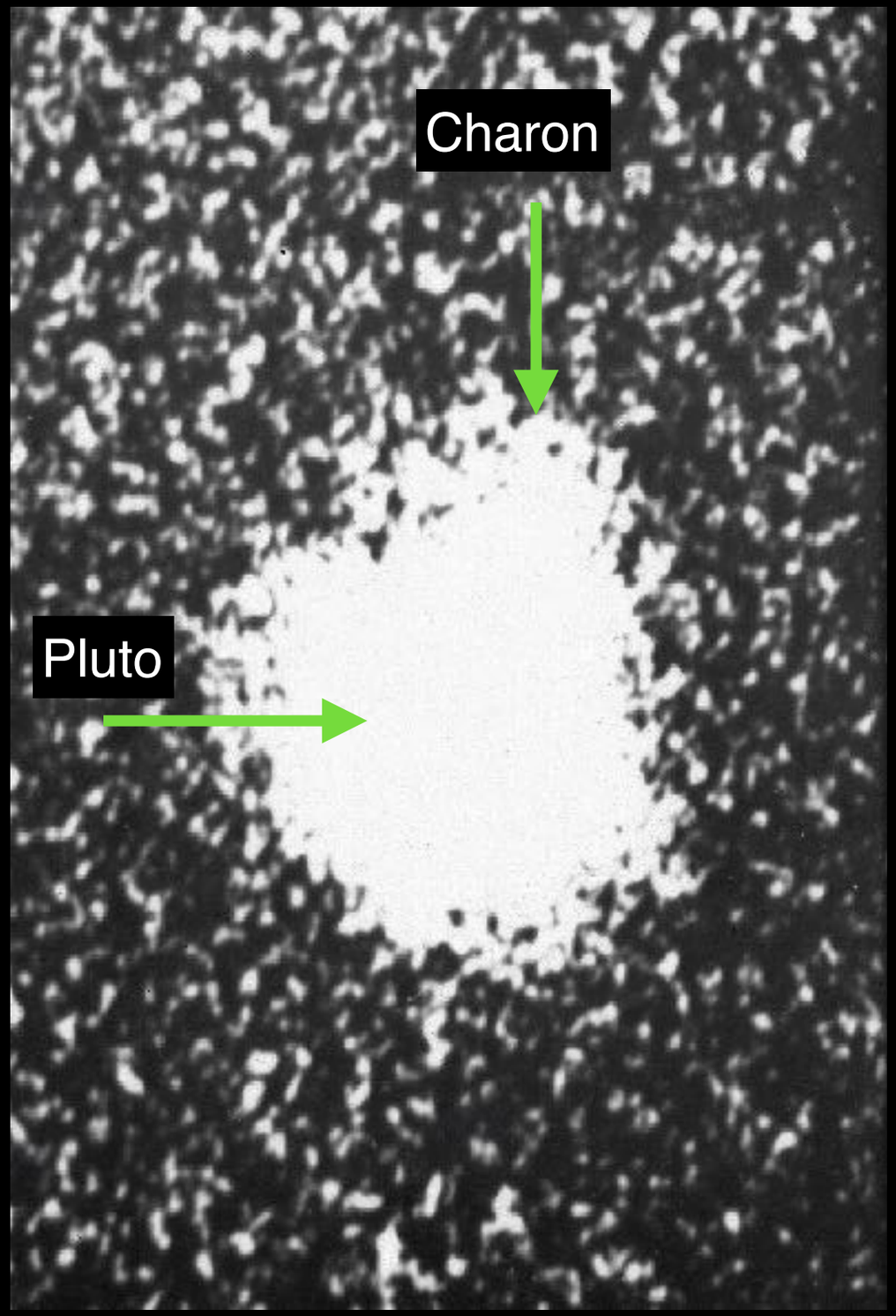
1905: Percival Lowell started the search for ‘Planet X’ at Lowell Observatory, Arizona, USA.

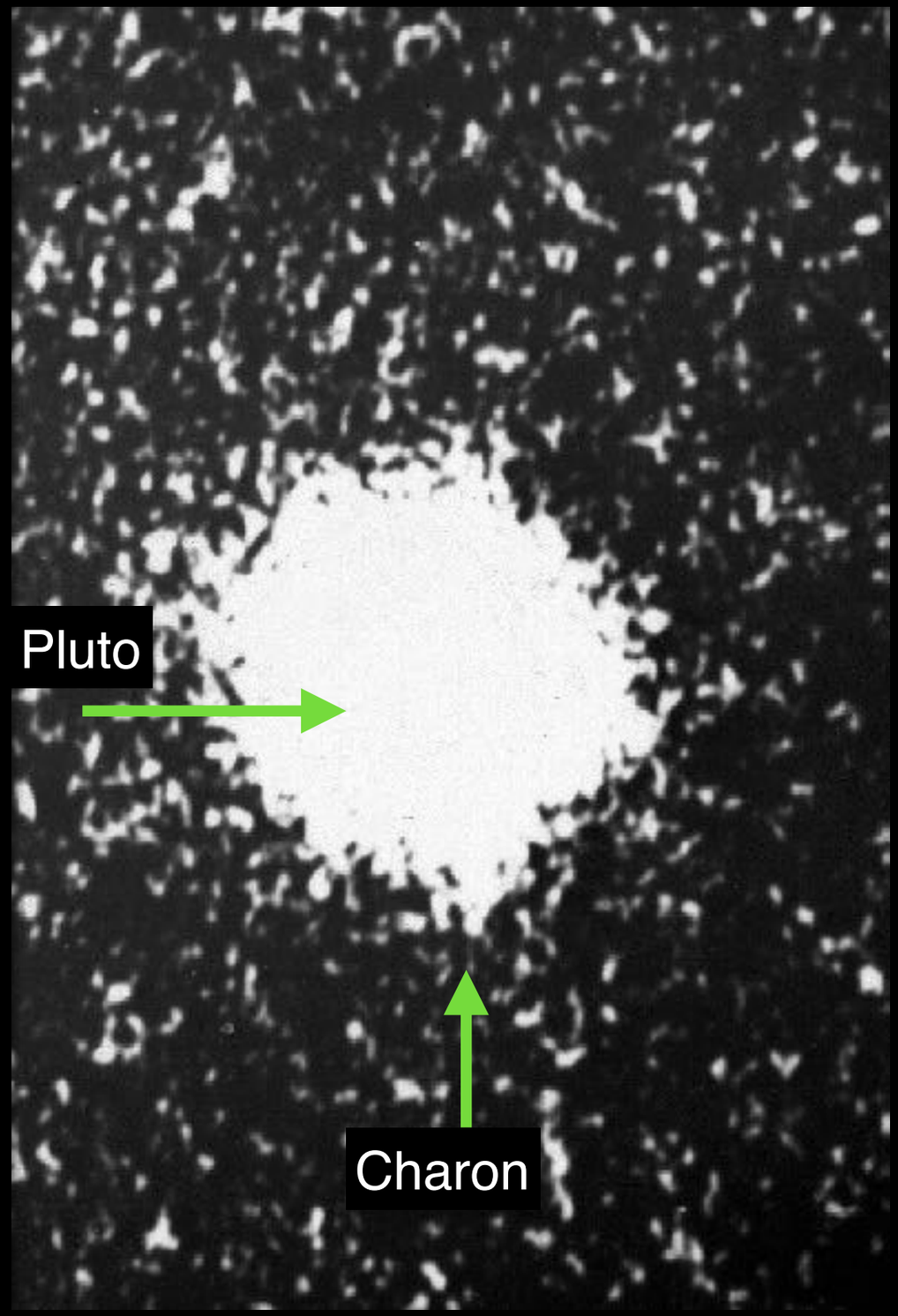


1925: Clyde Tombaugh is hired to search for Planet X at Lowell Observatory in Arizona.

13” Pluto Discovery Telescope, Lowell Observatory

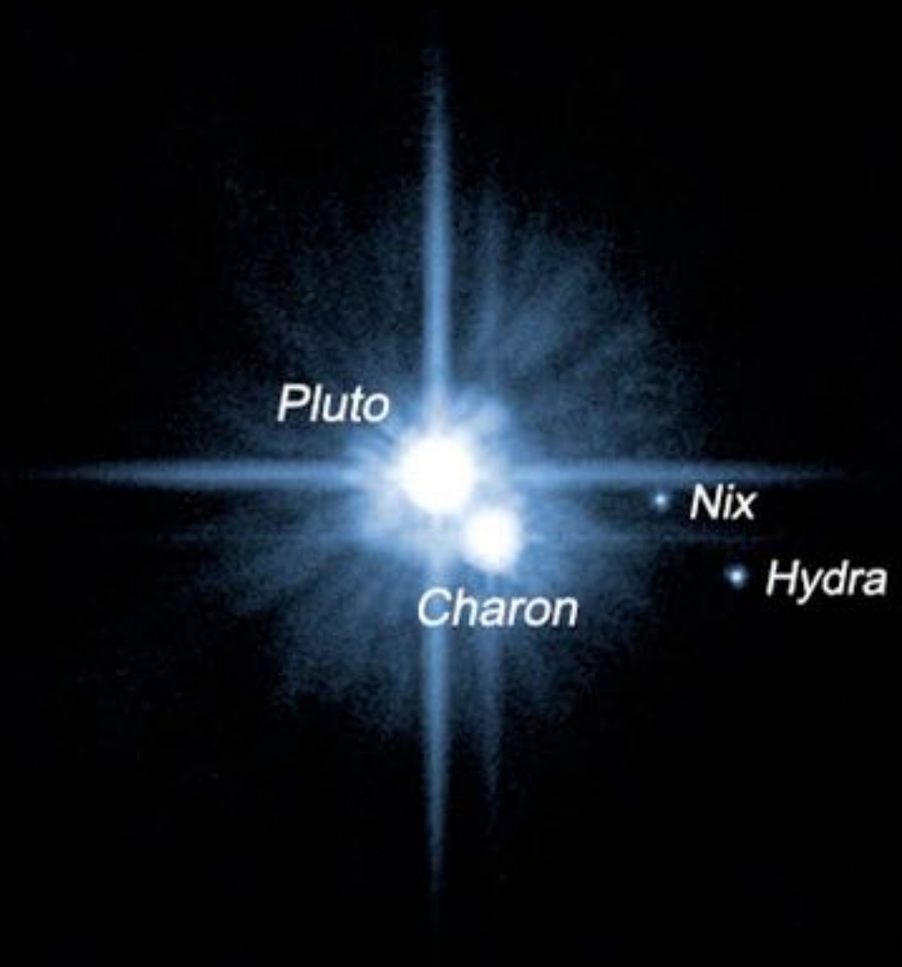




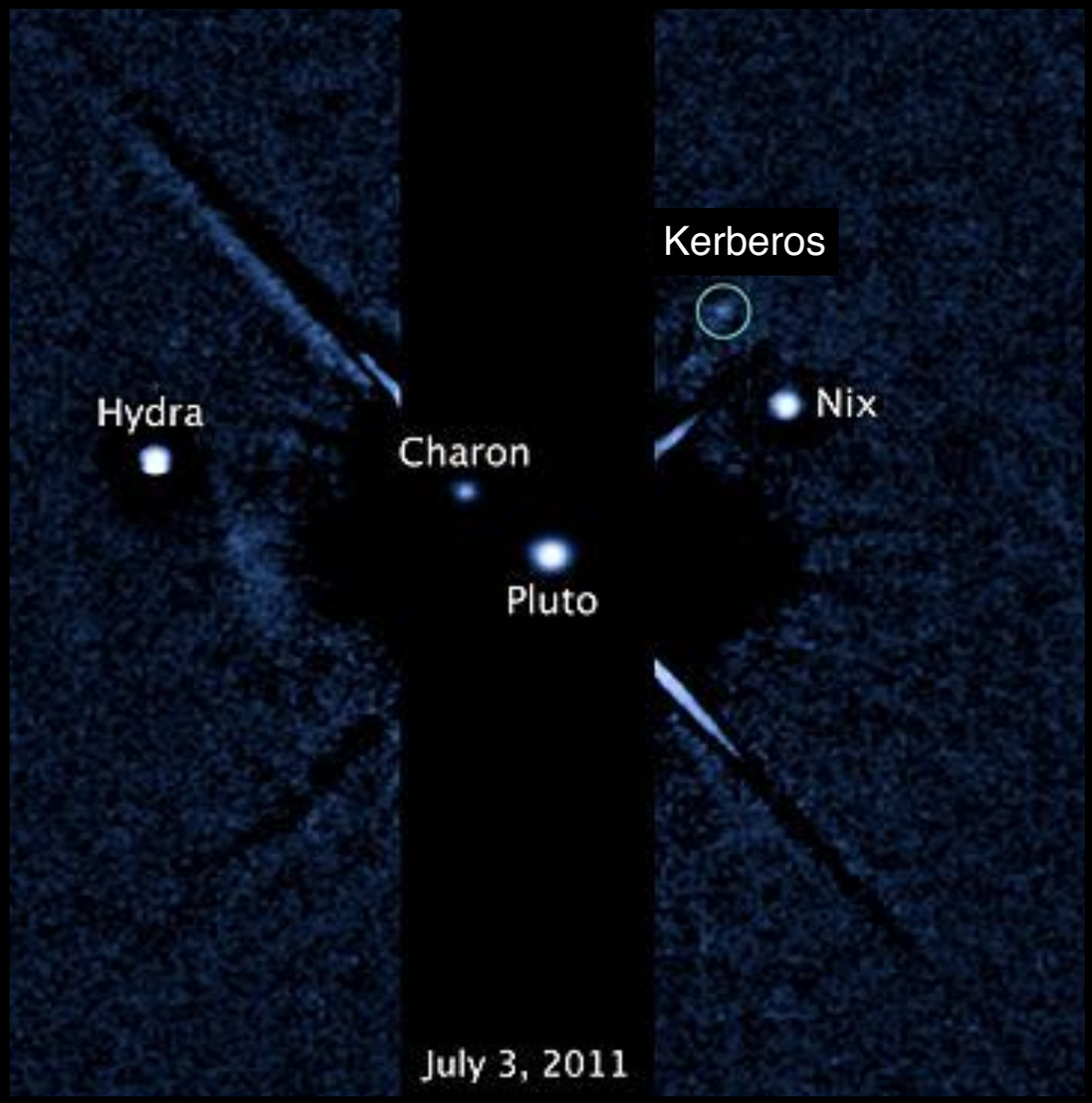


1978: Jim Christy discovers Pluto's moon Charon, orbiting Pluto every 6.5 days

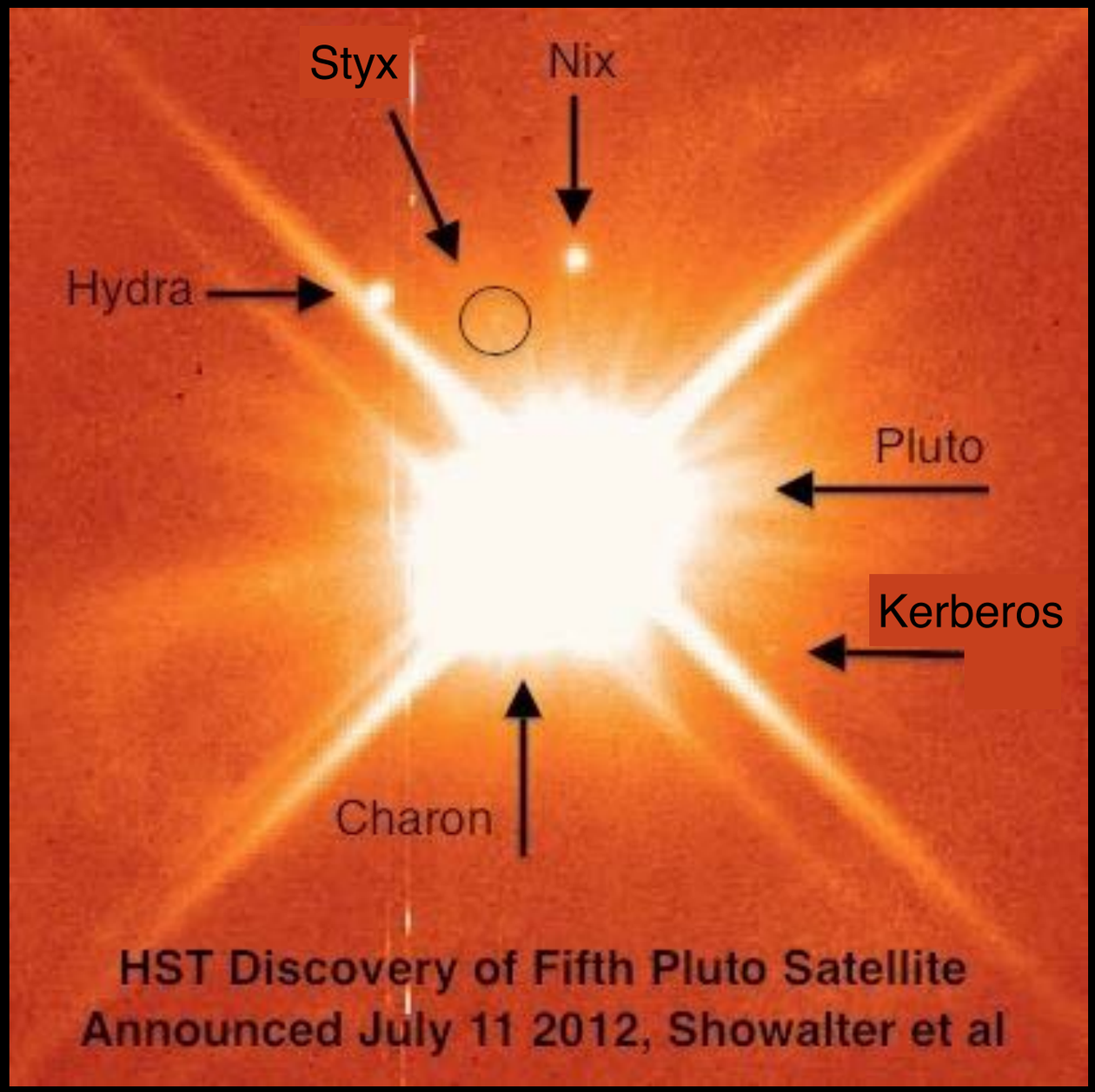
1930: Pluto
1978: Pluto + Charon Discovered



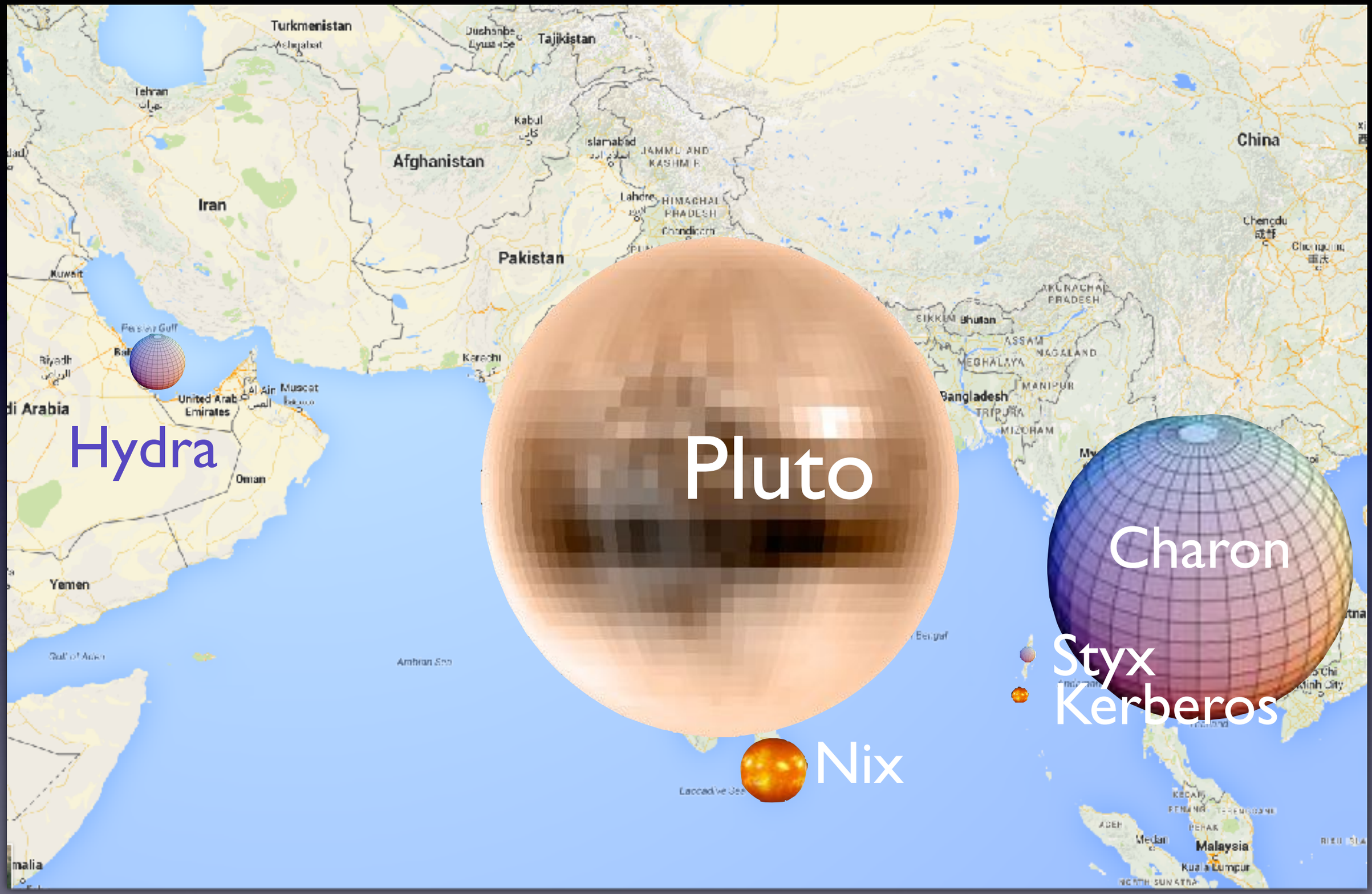
1930: Pluto
1978: Pluto + Charon
2006: Pluto + Charon + Nix + Hydra Discovered



1930: Pluto
1978: Pluto + Charon
2006: Pluto + Charon + Nix + Hydra
2011: Pluto + Charon + Nix + Hydra + Kerberos

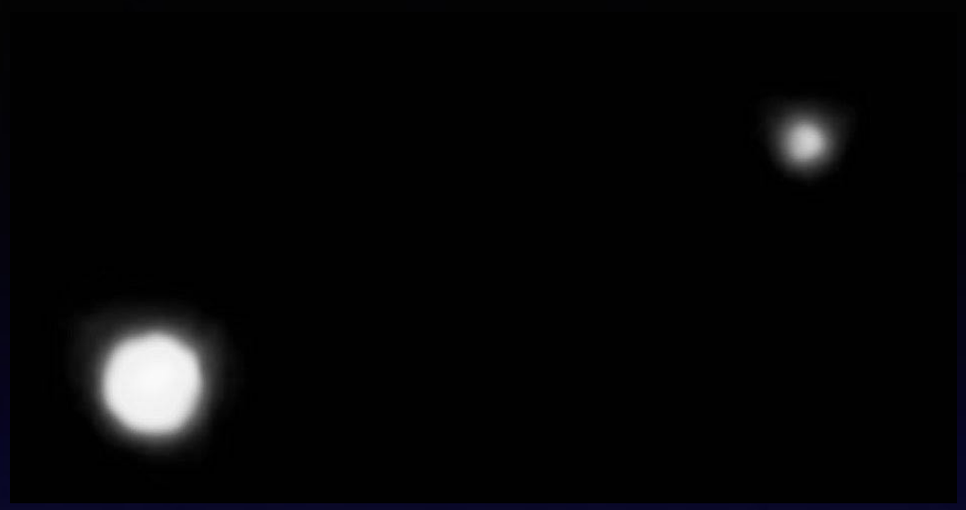


1930: Pluto
1978: Pluto + Charon
2006: Pluto + Charon + Nix + Hydra
2011: Pluto + Charon + Nix + Hydra + Kerberos
2012: Pluto + Charon + Nix + Hydra + Kerberos + Styx


Turkmenistan
Tajikistan
Tehran
Kabul
Afghanistan
Islamabad
China
Iran
Lahore
Pakistan
Kuwait
Karachi
Riyadh
United Arab Emirates
Muscat
Oman
Yemen
Bangladesh
Bhutan
Malaysia
Kuala Lumpur
Hydra
Pluto
Charon
Styx
Kerberos
Nix

Everything We Knew About Pluto on One Slide

- Radius ~1200 km
- Density ~ 2.0 g/cm^3
- 248 year orbital period, 6 day rotational period
- Surface: Nitrogen ice, with methane, CO, water, and some red organic goo ('tholins'). 40 K.
- Atmosphere: nitrogen, methane, CO, ~ 1/100,000 of Earth atmosphere
- Five bodies! Pluto, Charon, Nix, Hydra, Kerberos, Styx
- No known terrain or geological features.
- Pluto's small size means it cools quickly. No heat is left from formation, and minimal solar heating, means surface will be cold and ancient — 'geologically dead.'

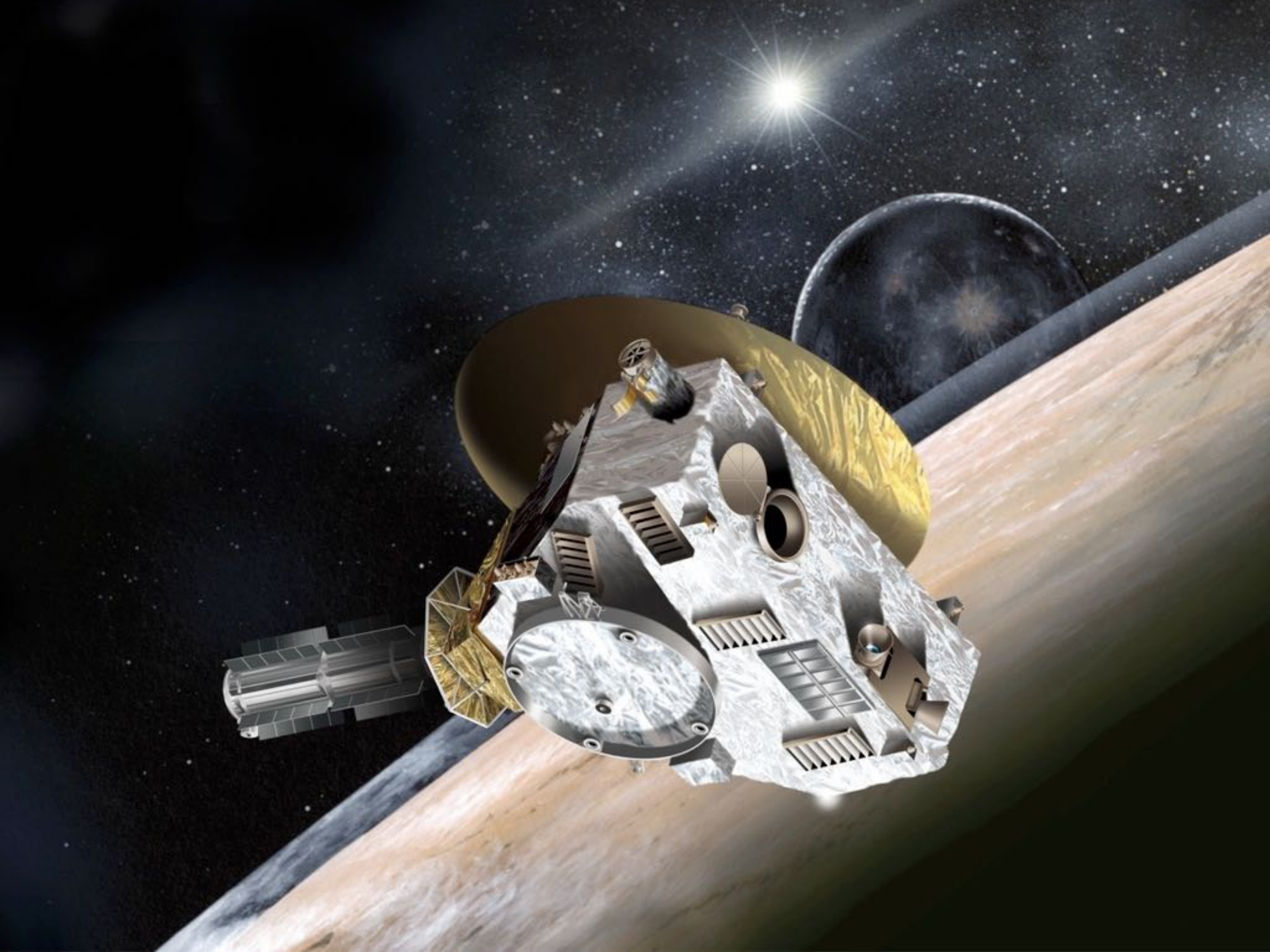


More exploration requires a close-up visit

Henry's Predictions for Pluto, c. 2012

- Because Pluto is small and far from the Sun, it will be cold.
- The cold surface and interior means no liquids, no oceans, no plate tectonics, no volcanoes... nothing young. Everything will be OLD!
- The thin atmosphere means no rivers, no oceans, no wind, no erosion... OLD!
- Surface will have a lot of impact craters, and not much else.

Indian Astronomical Observatory, Ladakh
4500 m elevation, 2.0 m mirror



New Horizons Spacecraft

$700M USD (Rs. 5000 cr), from NASA

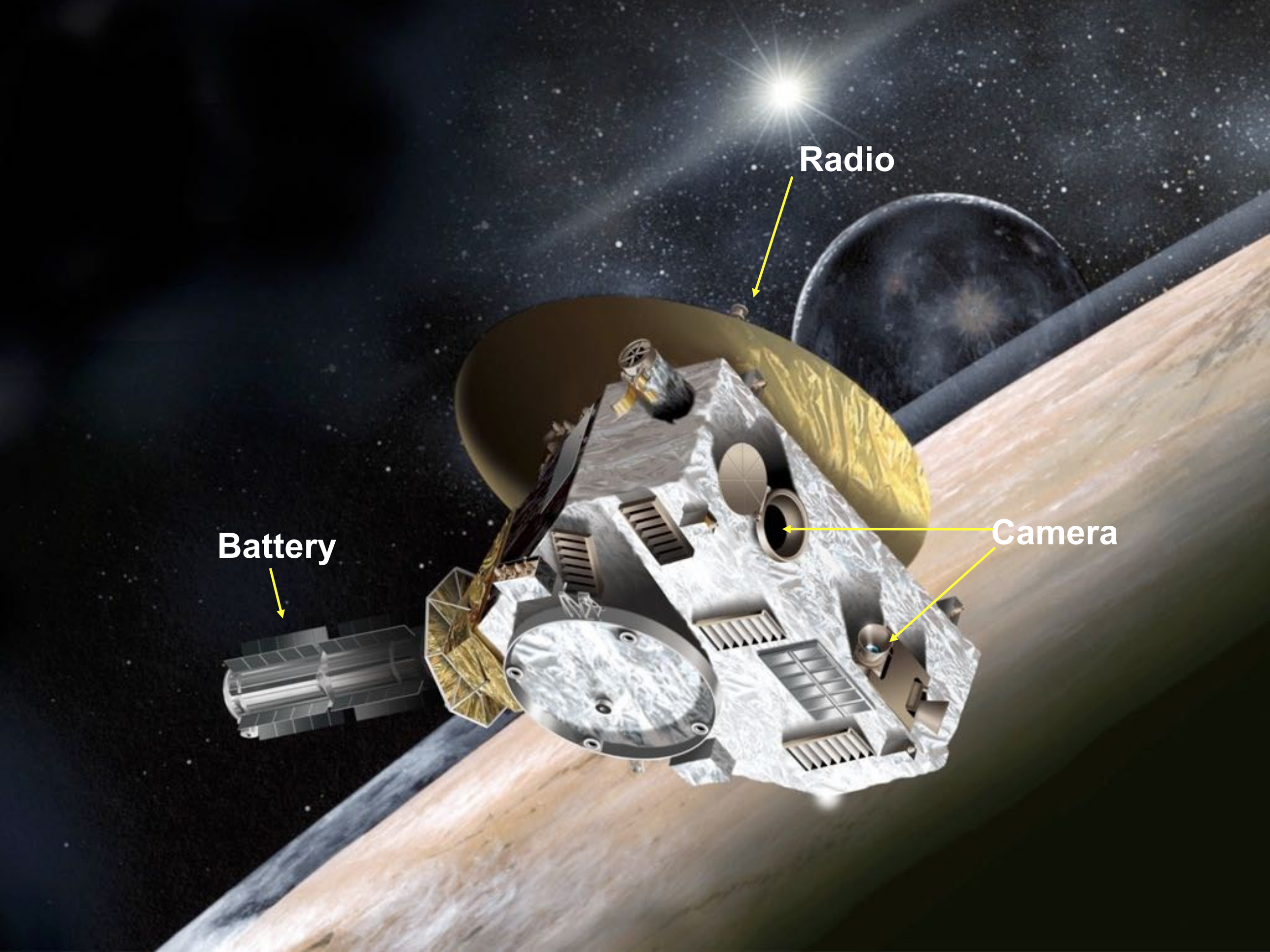
Size of a very small car

It is a robot - no people on it!

It flew past Pluto, took pictures, and sent them back over its radio.

It will keep flying - it doesn't land, and it never comes back to Earth.

New Horizons launched in 2006, and flew 6 billion km to Pluto, arriving in July 2015.


Radio
Battery
Camera


Camera
Radio
Battery
LTE
100%
9:41
Tuesday, September 9
Slide to unlock

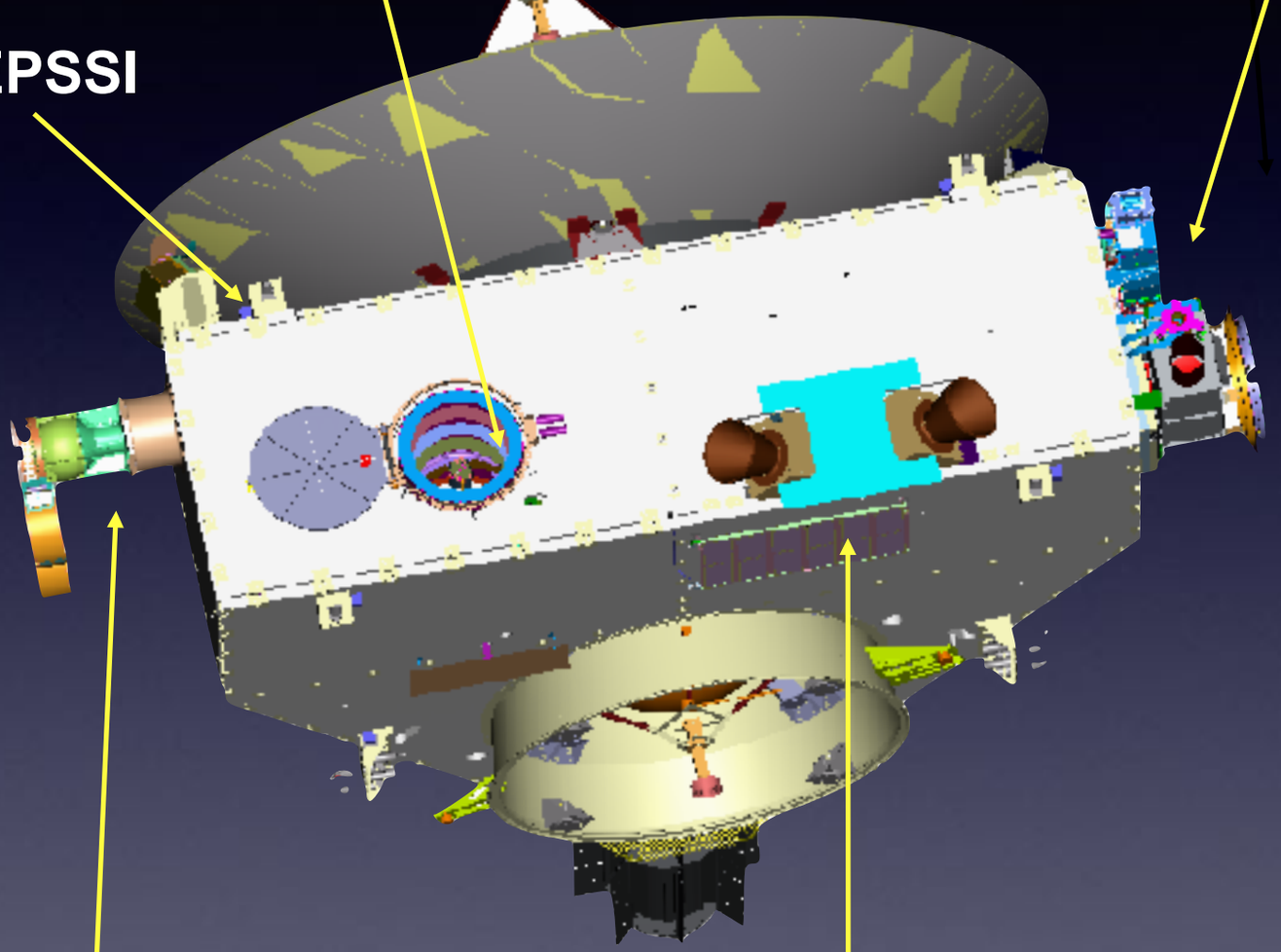
New Horizons Spacecraft

REX
(Radio Experiment)

LORRI
(Visible
Imager)

Alice
(UV Spectrometer)

PEPSSI

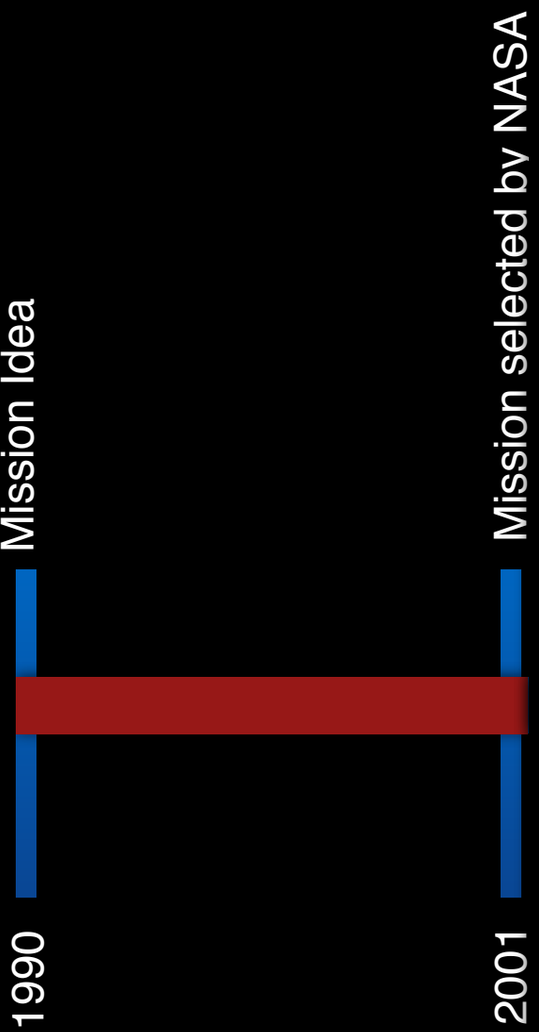


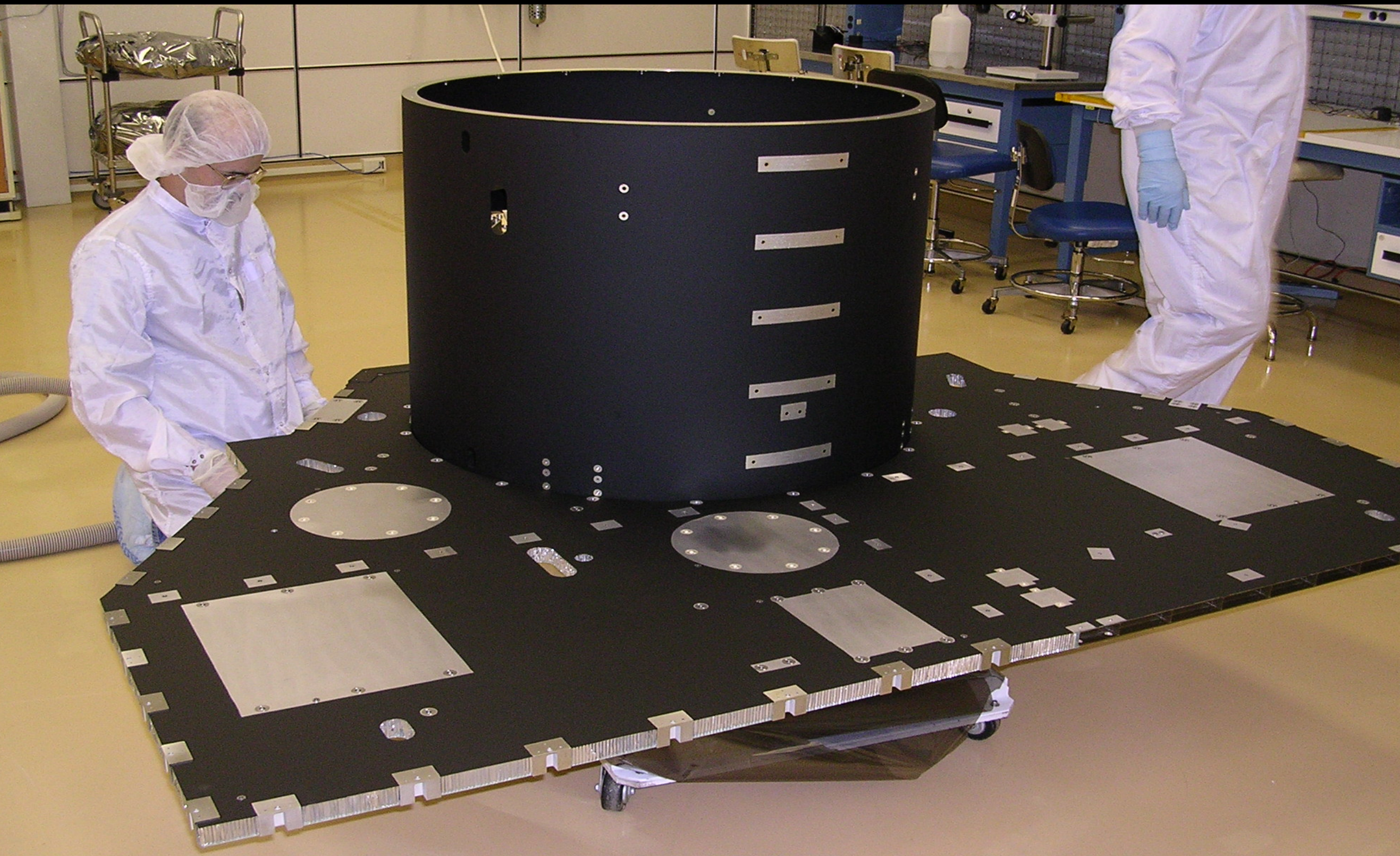
Ralph
(Visible / IR
Imager / Spectrometer)

SWAP
(Solar Wind)

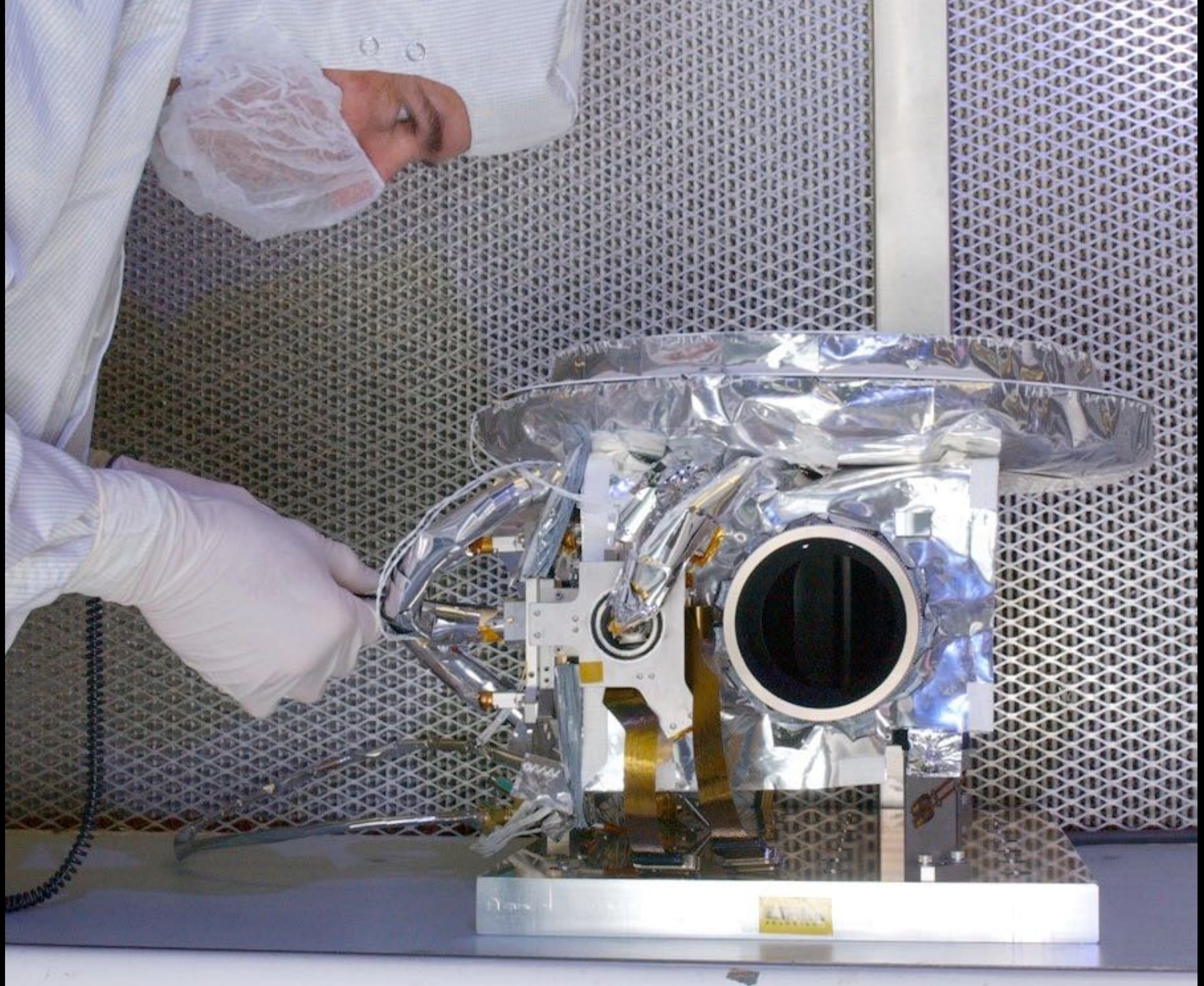
Student Dust
Counter

New Horizons Mission Timeline



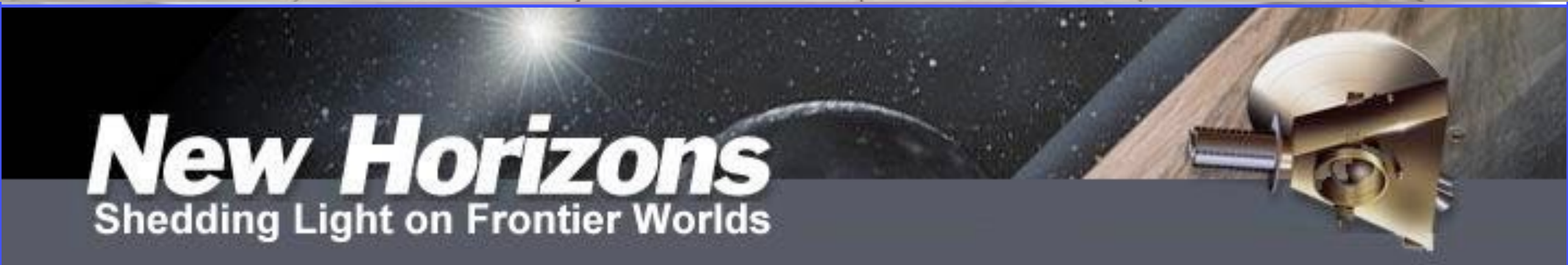


2002: Construction of spacecraft at JHU Applied Physics Lab (Laurel, MD) and other sites.



2005: Spacecraft is complete

New Horizons Team+



2006: Assemble launch vehicle at Cape Canaveral, Florida

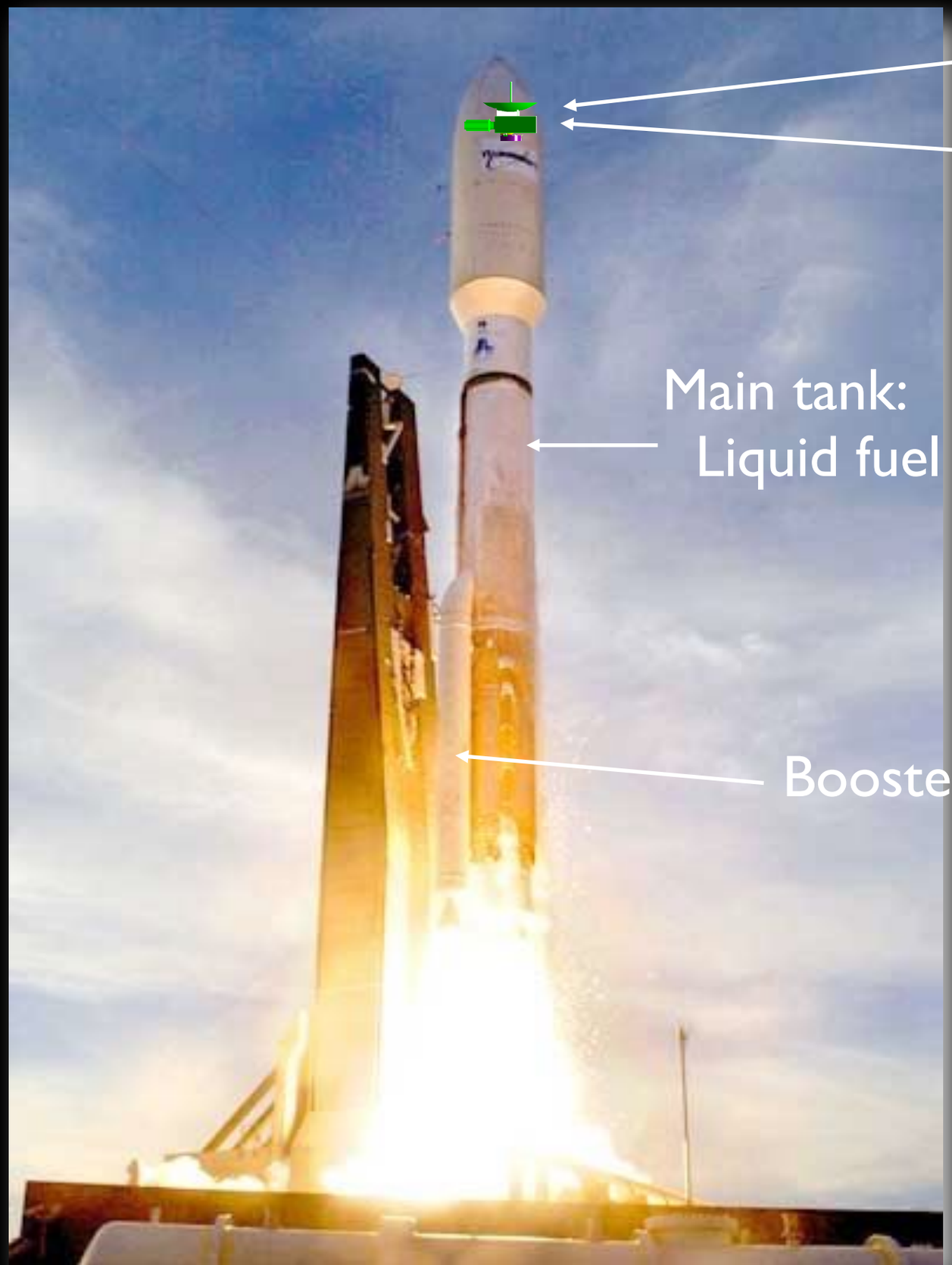
Lockheed-Martin Atlas V Rocket

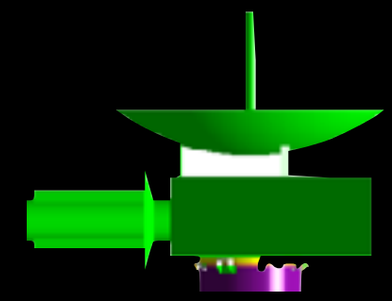
Rocket: 600,000 kg
Spacecraft: 478 kg
Cameras: 40 kg

Thrust: 2M pounds

Launch vehicle burns for 40 minutes and disconnects.

The next 9 1/2 years are an unpowered cruise to Pluto.






USAF


DO NOT FEED THE ALLIGATORS
ALLIGATORS BECOME AGGRESSIVE TOWARDS PEOPLE AND WILL HAVE TO BE DESTROYED


PLUTO
NEW HORIZONS
Canon
Canon
ULTRASONIC
CANON INC.
ET-86

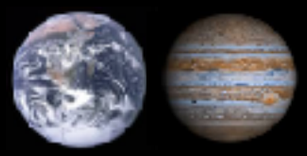

LOCKHEED MARTIN


NASA

New Horizons is the ***fastest*** spacecraft ever launched!

Vehicle	**Time to get to the Moon's distance**
Ferrari @ 250 kph	1600 hours
Apollo 11	100 hours
New Horizons	9 hours

New Horizons Mission Timeline



Mission

Mission selected by

Design

Construction

Construction

Testing

Launch

1990

2001

2002

2003

2004

2005

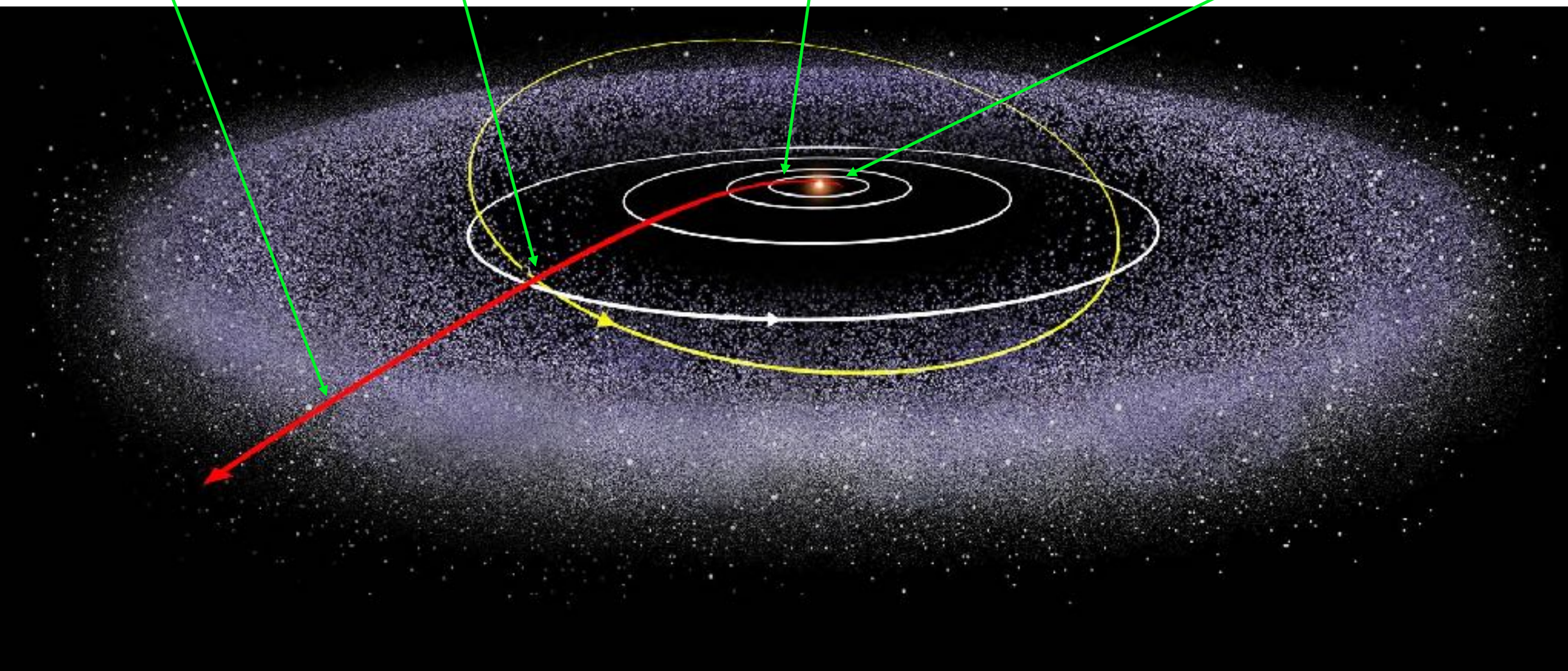
2006

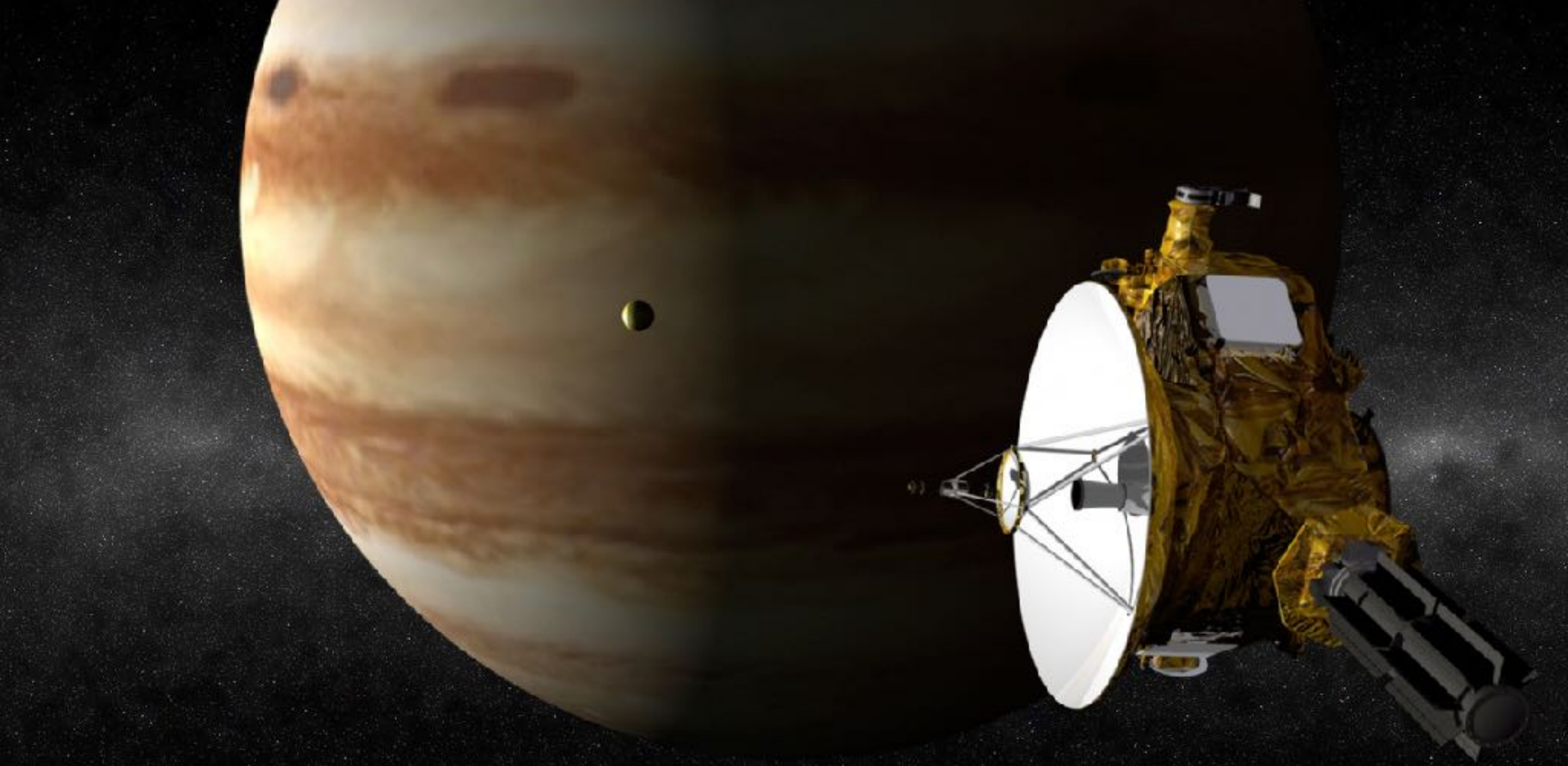
Pluto:
July 2015

Jupiter:
March 2007

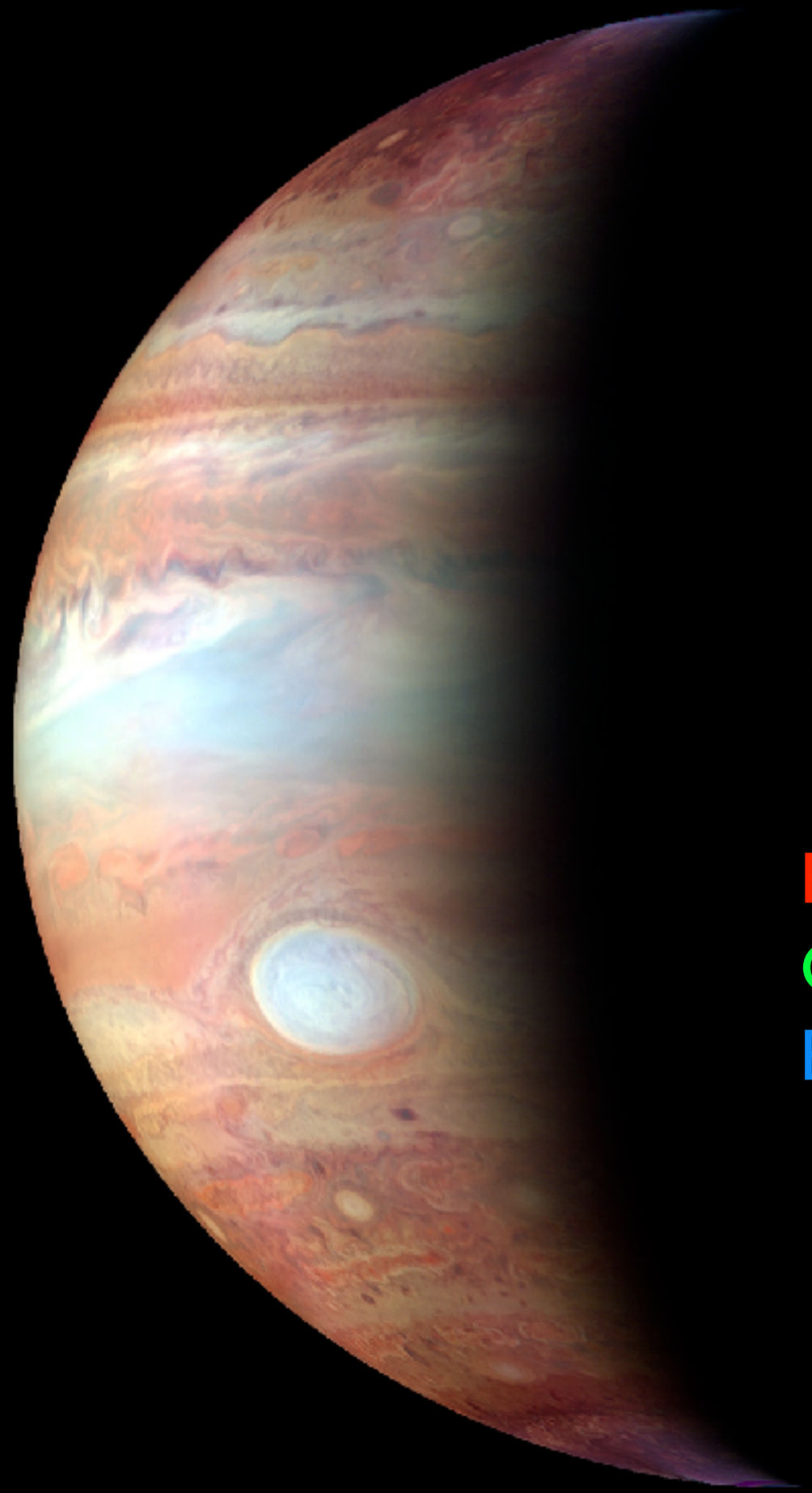
Kuiper Belt:
2016-2020

Earth:
January 2006





New Horizons at Jupiter: February 28 2007



New Horizon at Jupiter

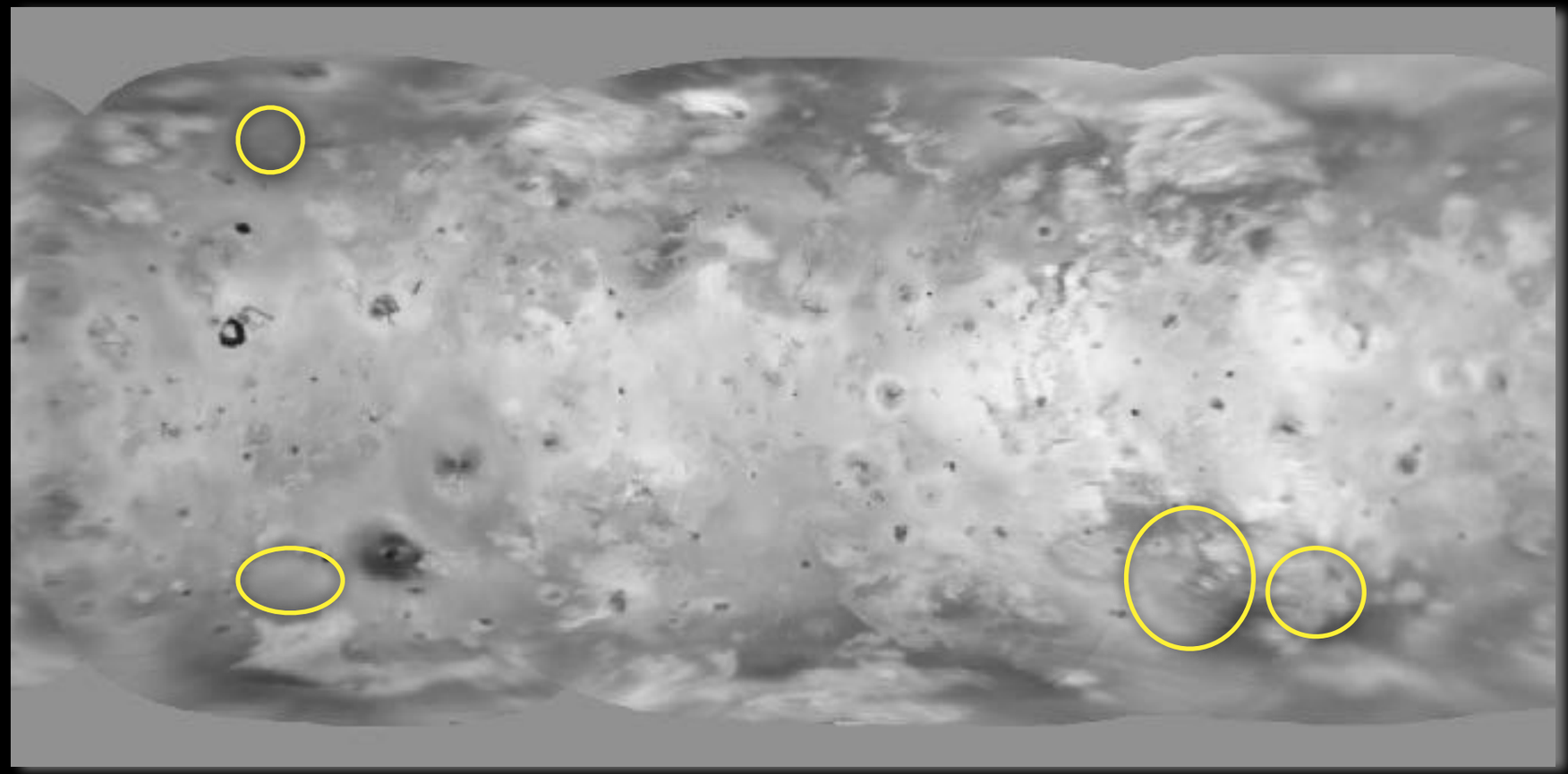
February 28, 2007

Red = 1.59 μm (Deep Clouds)
Green = 1.90 μm (Mid-level Clouds)
Blue = 1.85 μm (Upper-Level Hazes)

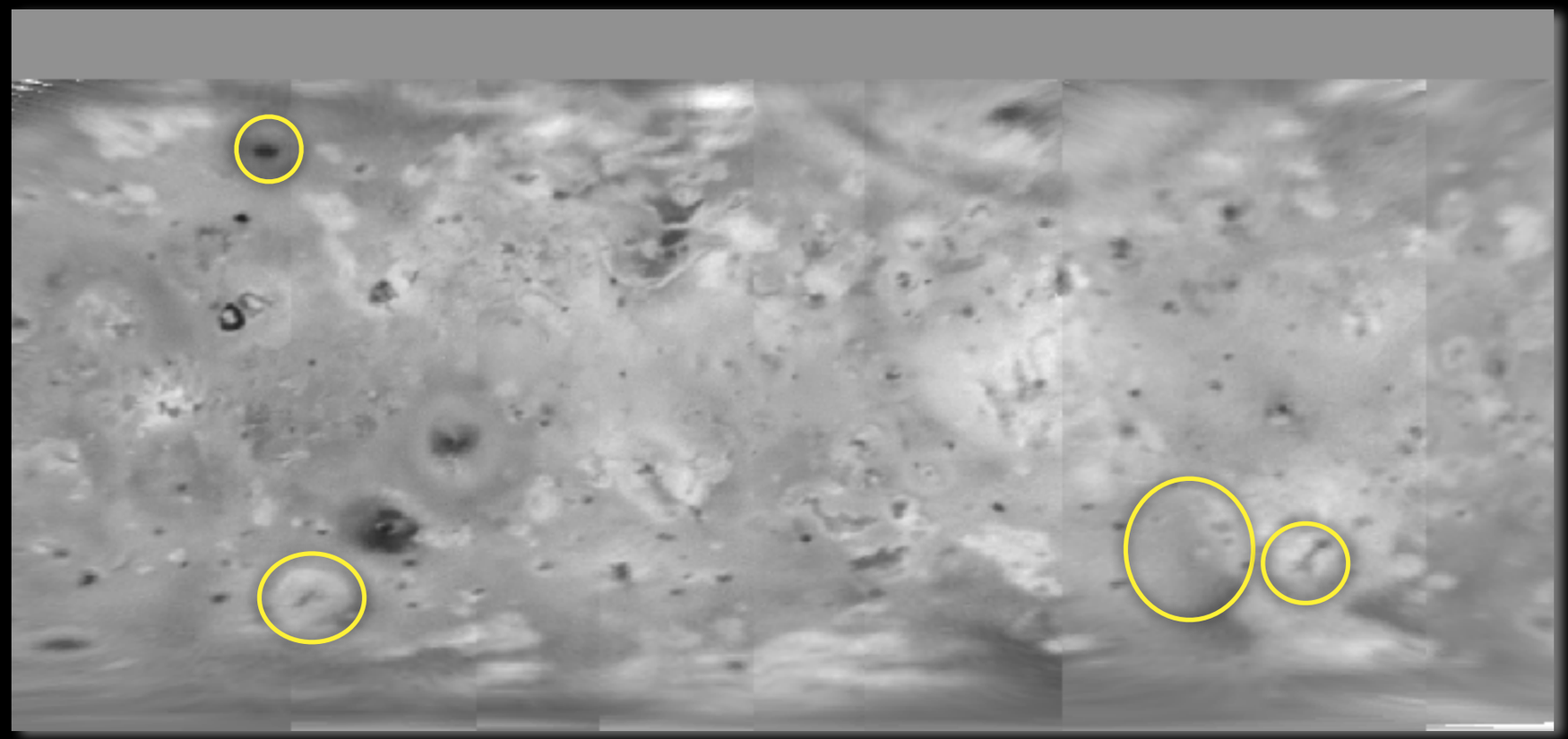
The rings of Jupiter, from New Horizons.

Ten Years of Surface Changes on Io

Galileo 1997

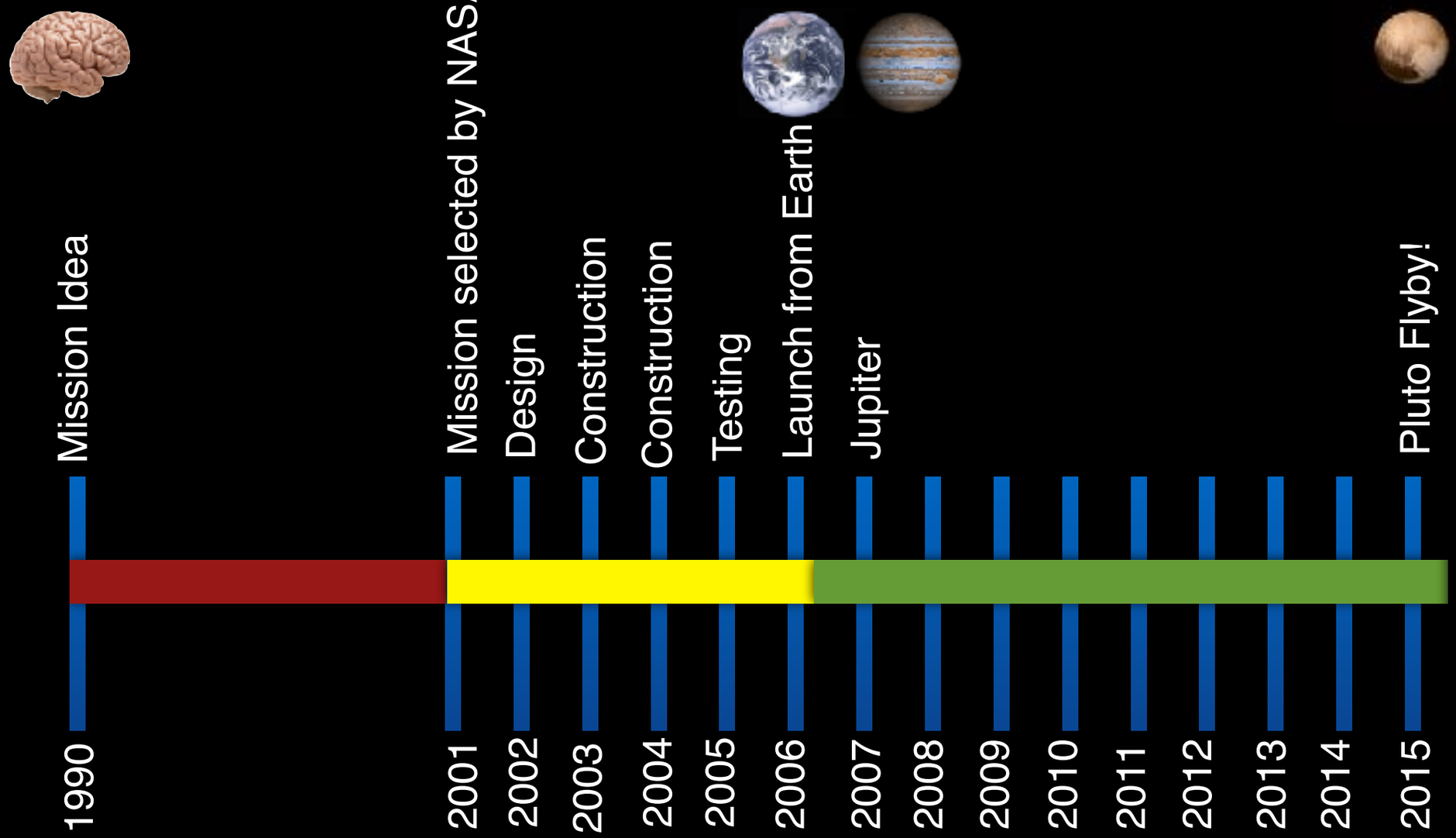


New Horizons 2007



Volcanoes on Io

We wait* for nine years while New Horizons flies 6 billion km…



*During these nine years we test the instruments, calibrate the data, plan the observations, perform dress rehearsals, test again, write software, upgrade systems, etc. — a very busy nine years!

My Roles During the Mission as a Member of the Science Team

Pre-launch (2001-2005)

- Calibration of infrared spectrometer

Cruise (2006 - 2014)

- Development of software tools to plan observations
- Searches for dust that would be a hazard to the spacecraft
- Planning observations

Encounter (2015)

- Searches for new satellites on approach
- Searches for rings on departure (backlit)

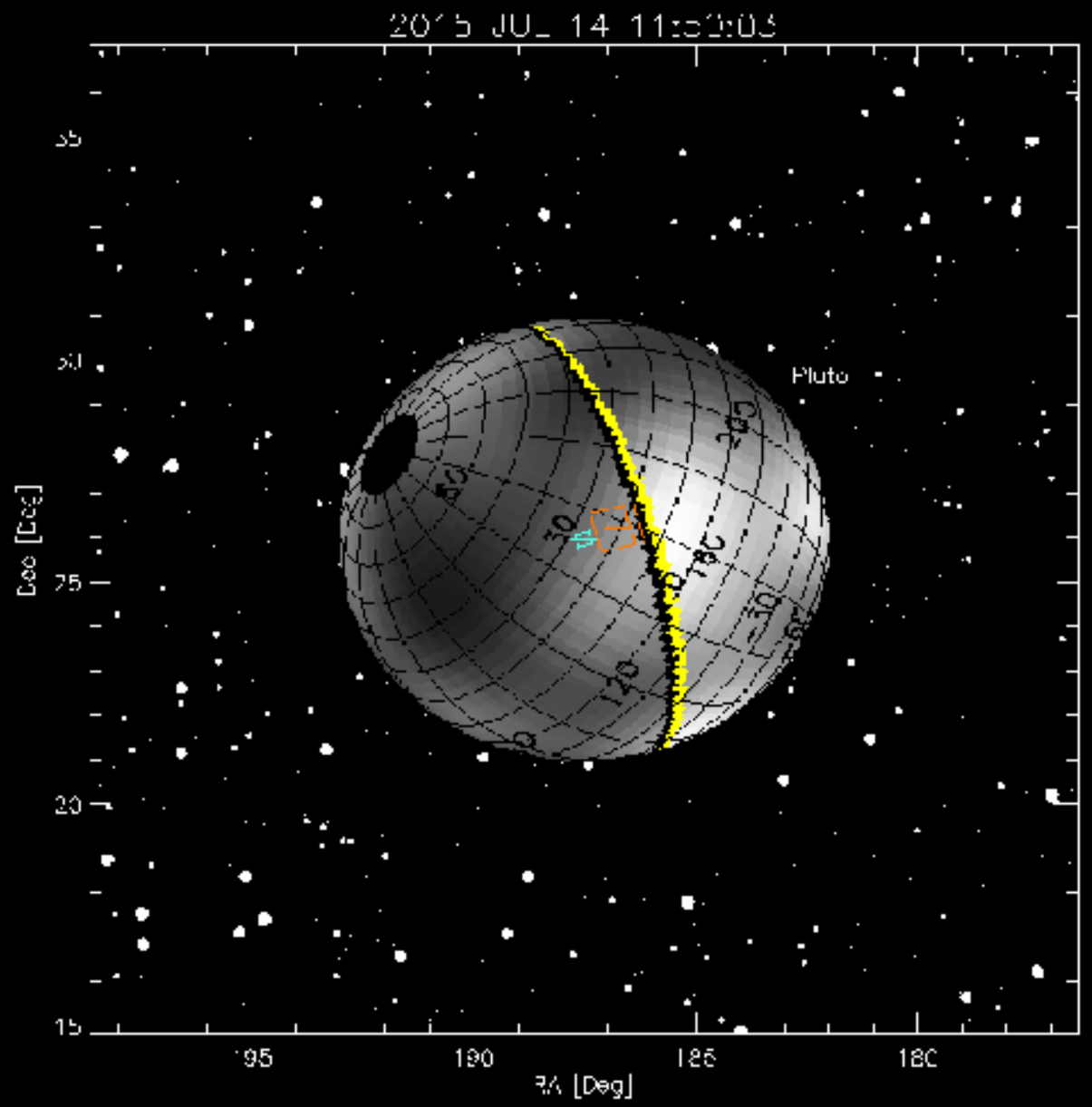
New Horizons GeoViz

Documentation News (29-Apr-2015)

Plot

Observer	New Horizons · Reference Metakernel Upload kernels
Times	Start 2015 Jul 14 11:50:03 End Interval 1 Timesteps Movie
Center Position	Target Pluto RA 187.62521 Dec 25.95802 Deg (H/D)MS Rad
Center FOV	LORRI CtrPlot on Target
FOV Position	dRA 0.0 dDec 0.0 Degrees from Target
FOV Footprints	
Plot FOVs	MVIC LEISA LORRI Alice Airglow Alice SOC PEPSSI SWAP REX Star Tracker 1 Star Tracker 2 S/C Boresight S/C Axes Mark Boresights Color FOVs Line Thickness 1 STK Colors
Plot Radius	2 Target Radii
Roll Angle	0.000 deg from Orbit Normal
Objects	Draw / Label / Orbits Stars Planets Satellites Barycenters
Stars	Stellar Catalog TYC2 Stellar Mag Lim / Range 9.0 Stellar Type Filter
Surface Style	Albedo
Projection	Rectangular
Show Data Tables	
Ref Frame J2000	Downtrack Error Seconds
Plot Size 700 Pixels	Plot Title
Flip RA White sky List kernel info Pluto RHR	

Reset Inputs to Defaults Plot

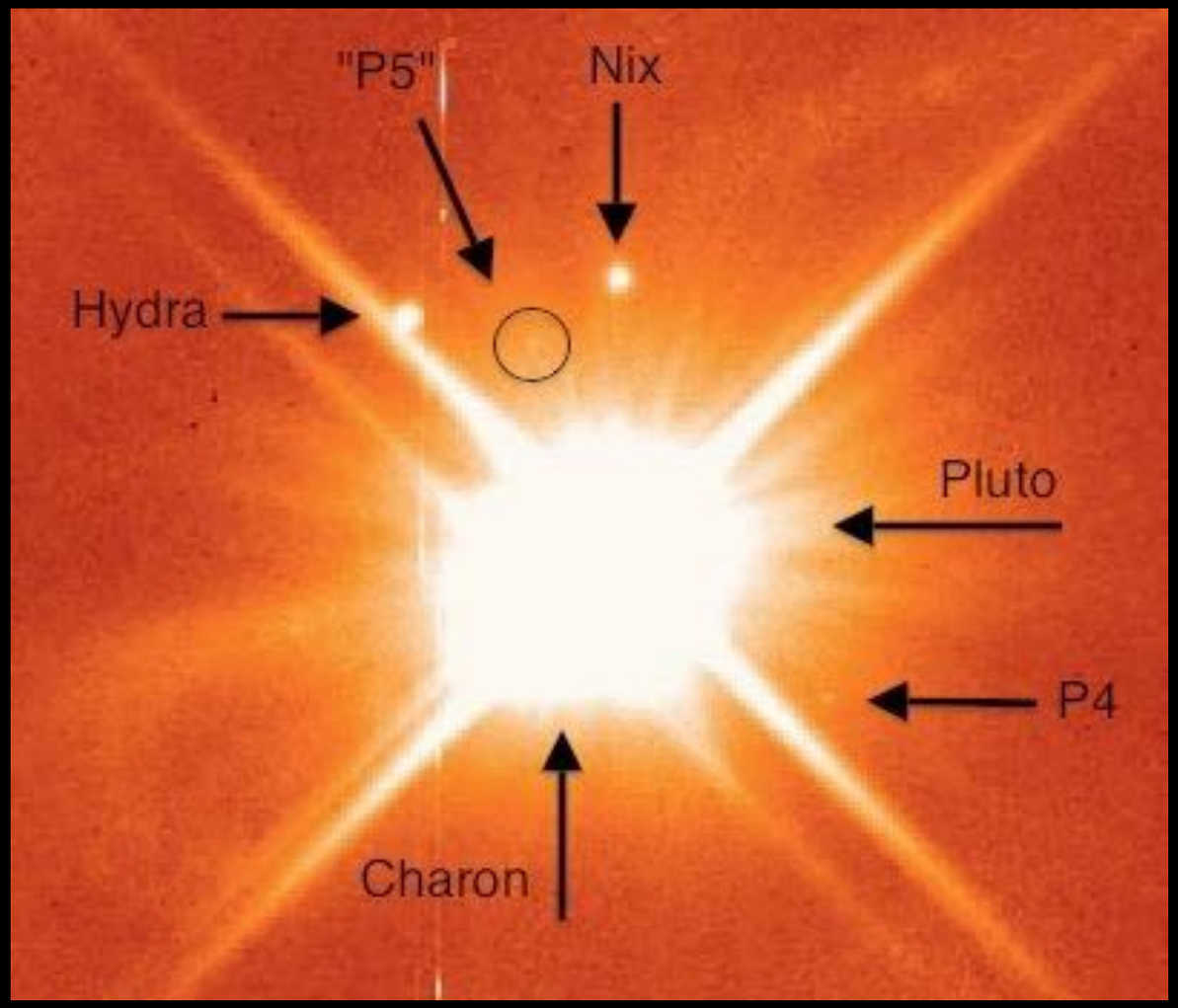


Download as PNG

Five Missions for the Price of One

- 2001: When New Horizons was selected by NASA, Pluto had just one known moon, Charon.
- 2005: Two new moons discovered: Nix and Hydra
- 2006: Launch
- 2011: One more moon discovered: Kerberos
- 2012: One more moon moon discovered: Styx

All these new moons are great, but they give us a big problem...



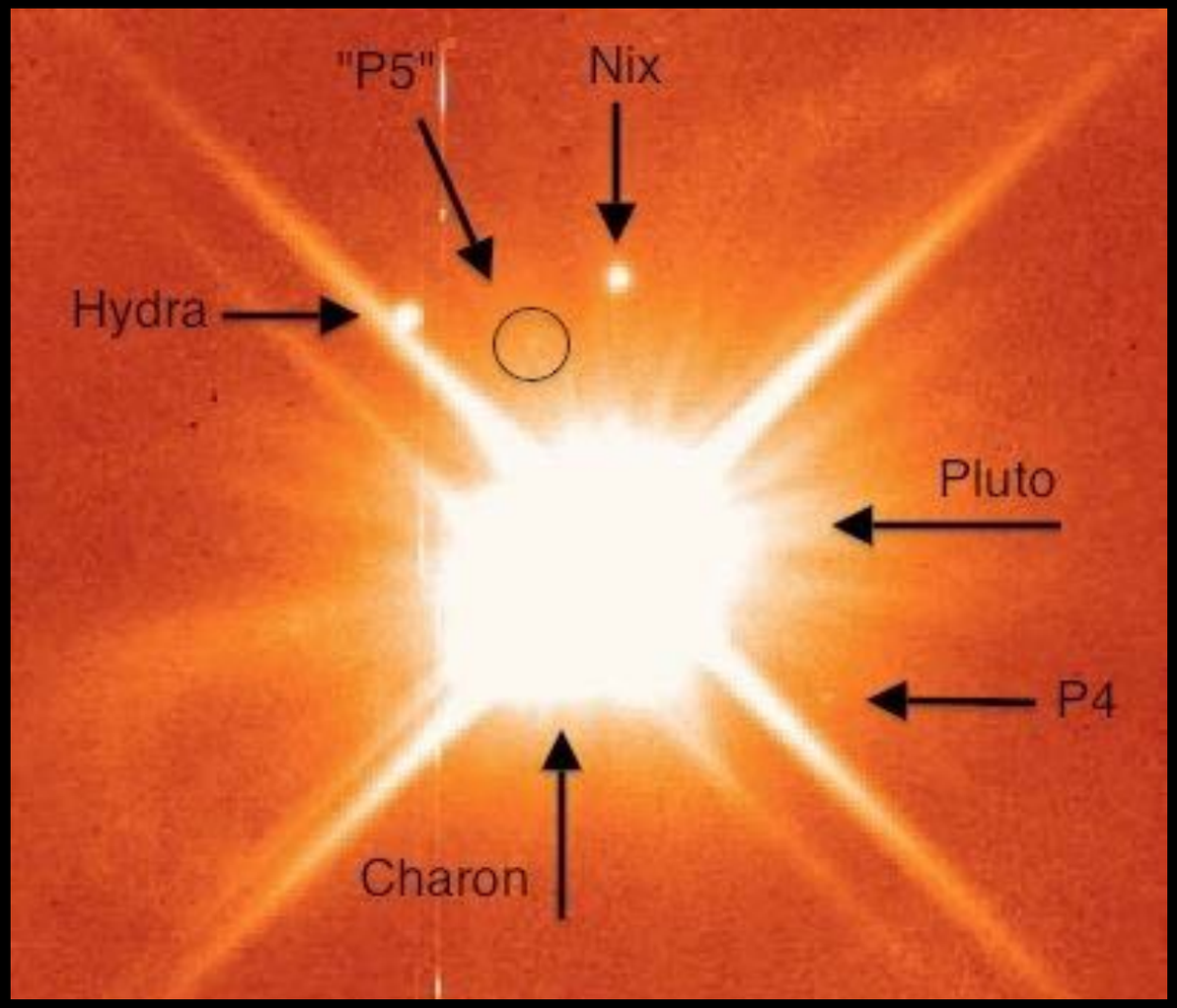
If there are five moons, there may be more moons, more rocks, more dust that we cannot see... and *that* could be dangerous.

A dust particle this tiny can end the mission.

We can't see millimeter-sized dust grains at Pluto -- they are too small!

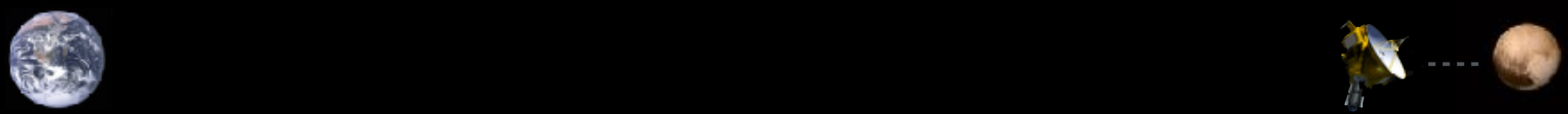
But we searched for dust clouds using Hubble, and using New Horizons itself.

And we did computer modeling to study the orbits of dust particles at Pluto... making a prediction whether Pluto has 'rings' of dust, or not.



Conclusion: Disaster averted. After much work, we concluded that space around Pluto was not dusty, and we could fly New Horizons past the planet like planned.

By early 2015, New Horizons had traveled about 5.5 billion km. It was finally close enough to Pluto that it could see it better than Hubble can.



April 14, 2015

First Pluto-Charon Color Image from New Horizons

This image of Pluto and its largest moon, Charon, was taken by the Ralph color imager aboard NASA's New Horizons spacecraft on April 9 and downlinked to Earth the following day. It is the first color image ever made of the Pluto system by a spacecraft on approach. The image is a preliminary reconstruction, which will be refined later by the New Horizons science team. Clearly visible are both Pluto and the Texas-sized Charon. The image was made from a distance of about 71 million miles (115 million kilometers)—roughly the distance from the Sun to Venus. At this distance, neither Pluto nor Charon is well resolved by the color imager, but their distinctly different appearances can be seen. As New Horizons approaches its flyby of Pluto on July 14, it will deliver color images that eventually show surface features as small as a few miles across.

Credit: NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute

15-Apr-2015

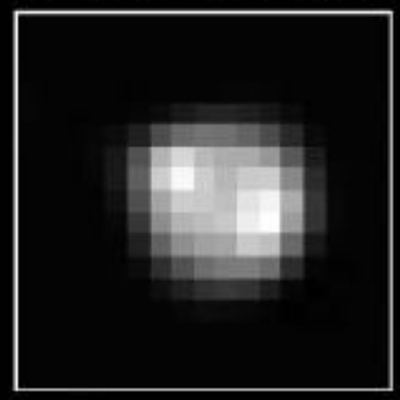
NH LORRI OPTICAL NAVIGATION CAMPAIGN 3

PROPER MOTION - IMAGE DECONVOLVED

2015-04-15 03:34:00 UTC

DISTANCE: 107,597,728 KM
CLOSEST APPROACH: 90.34 days

Pluto Zoom x3



April 30, 2015

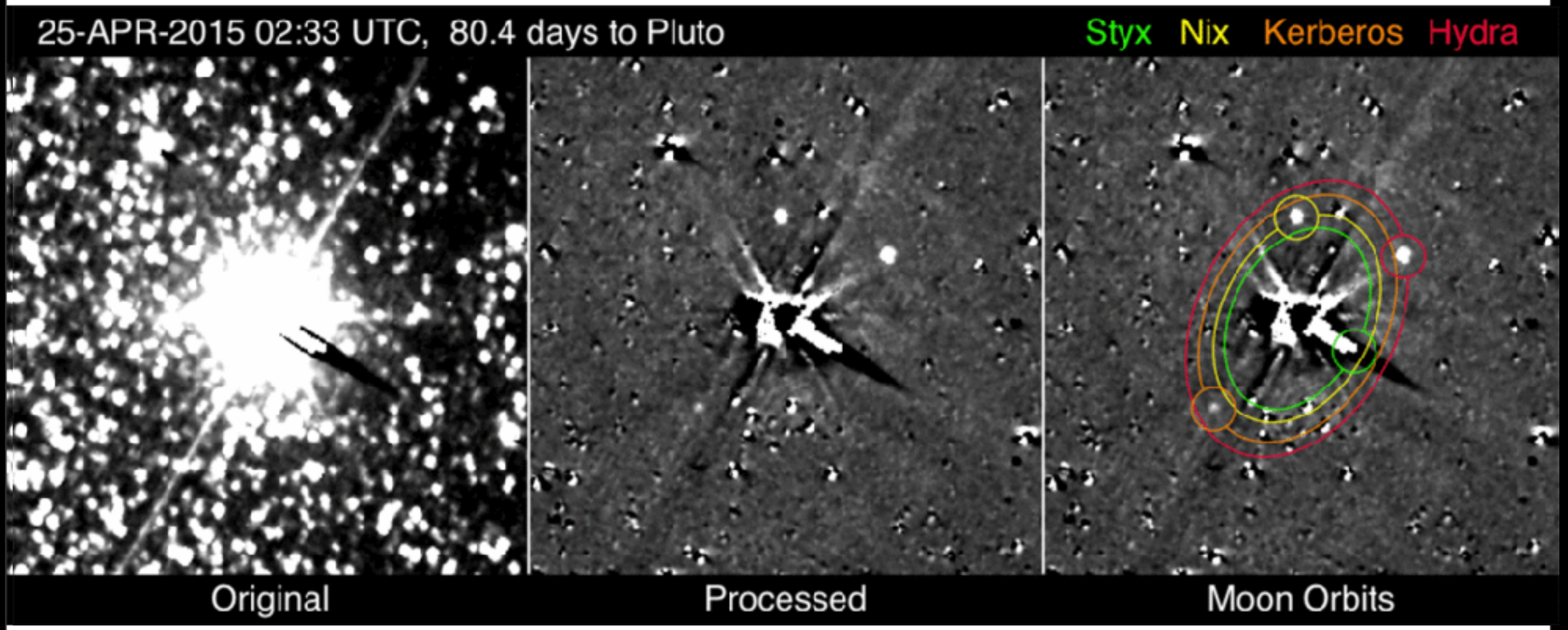
New Horizons Sees Pluto and Charon

This series of New Horizons images of Pluto and its largest moon, Charon, was taken at 13 different times spanning 6.5 days, starting on April 12 and ending on April 18, 2015. During that time, the NASA spacecraft's distance from Pluto decreased from about 69 million miles (111 million kilometers) to 64 million miles (104 million kilometers).

The pictures were taken with the New Horizons Long Range Reconnaissance Imager, or LORRI. Pluto and Charon rotate around a center-of-mass (also called the "barycenter") once every 6.4 Earth days, and these LORRI images capture one complete rotation of the system.

May 12, 2015

NASA's New Horizons Spots Pluto's Faintest Known Moons



It's a complete Pluto family photo – or at least a photo of the family members we've already met.

For the first time, NASA's New Horizons spacecraft has photographed Kerberos and Styx – the smallest and faintest of Pluto's five known moons. Following the spacecraft's detection of Pluto's giant moon Charon in July 2013, and Pluto's smaller moons Hydra and Nix in July 2014 and January 2015, respectively, New Horizons is now within sight of all the known members of the Pluto system.

"New Horizons is now on the threshold of discovery," said mission science team member John Spencer, of the Southwest Research Institute in Boulder, Colorado. "If the spacecraft observes any additional moons as we get closer to Pluto, they will be worlds that no one has seen before."

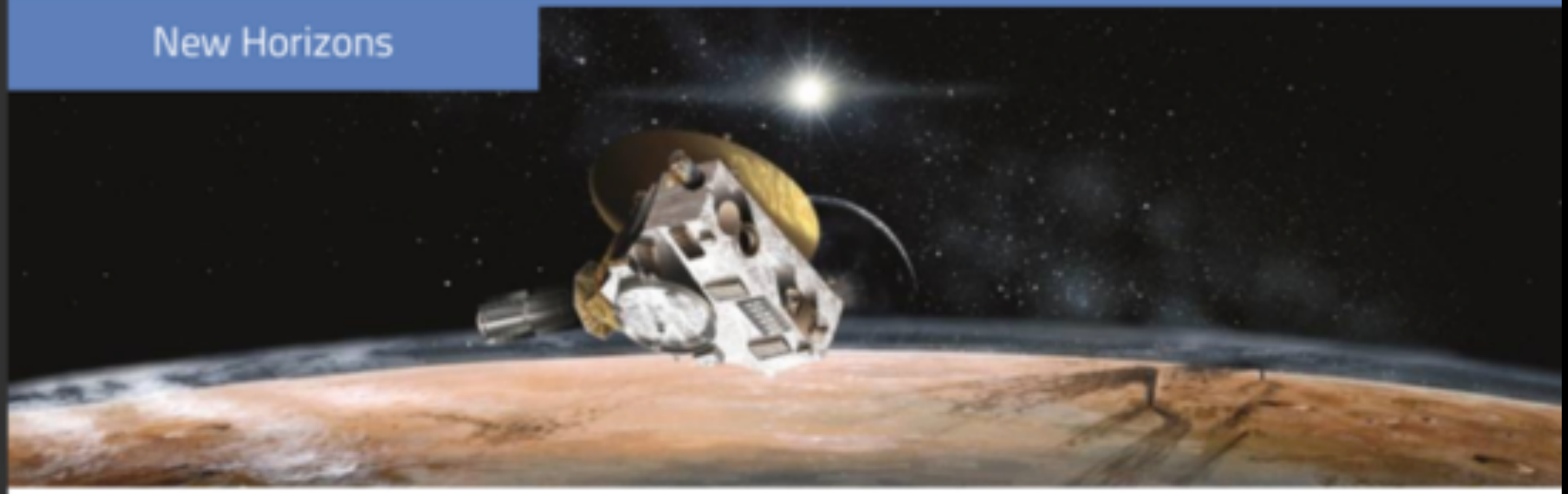
Drawing ever closer to Pluto in mid-May, New Horizons will begin its first search for new moons or rings that might threaten the spacecraft on its passage through the Pluto system. The images of faint Styx and Kerberos shown here are allowing the search team to refine the techniques they will use to analyze those data, which will push the sensitivity limits even deeper.

June 27, 2015

01:54:12 PM EDT 04 Jul 2015

Carrier lost - no signal found

New Horizons



July 4, 2015

New Horizons Team Responds to Spacecraft Anomaly

The New Horizons spacecraft experienced an anomaly the afternoon of July 4 that led to a loss of communication with Earth. Communication has since been reestablished and the spacecraft is healthy.

The mission operations center at the Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland, lost contact with the unmanned spacecraft -- now 10 days from arrival at Pluto -- at 1:54 p.m. EDT,

NewHorizons2015
@NewHorizons2015

Follow

New Horizons in safe mode. We're working it folks. nasa.gov/nh/new-horizon…

Alice Bowman, New Horizons Mission Operations Manager

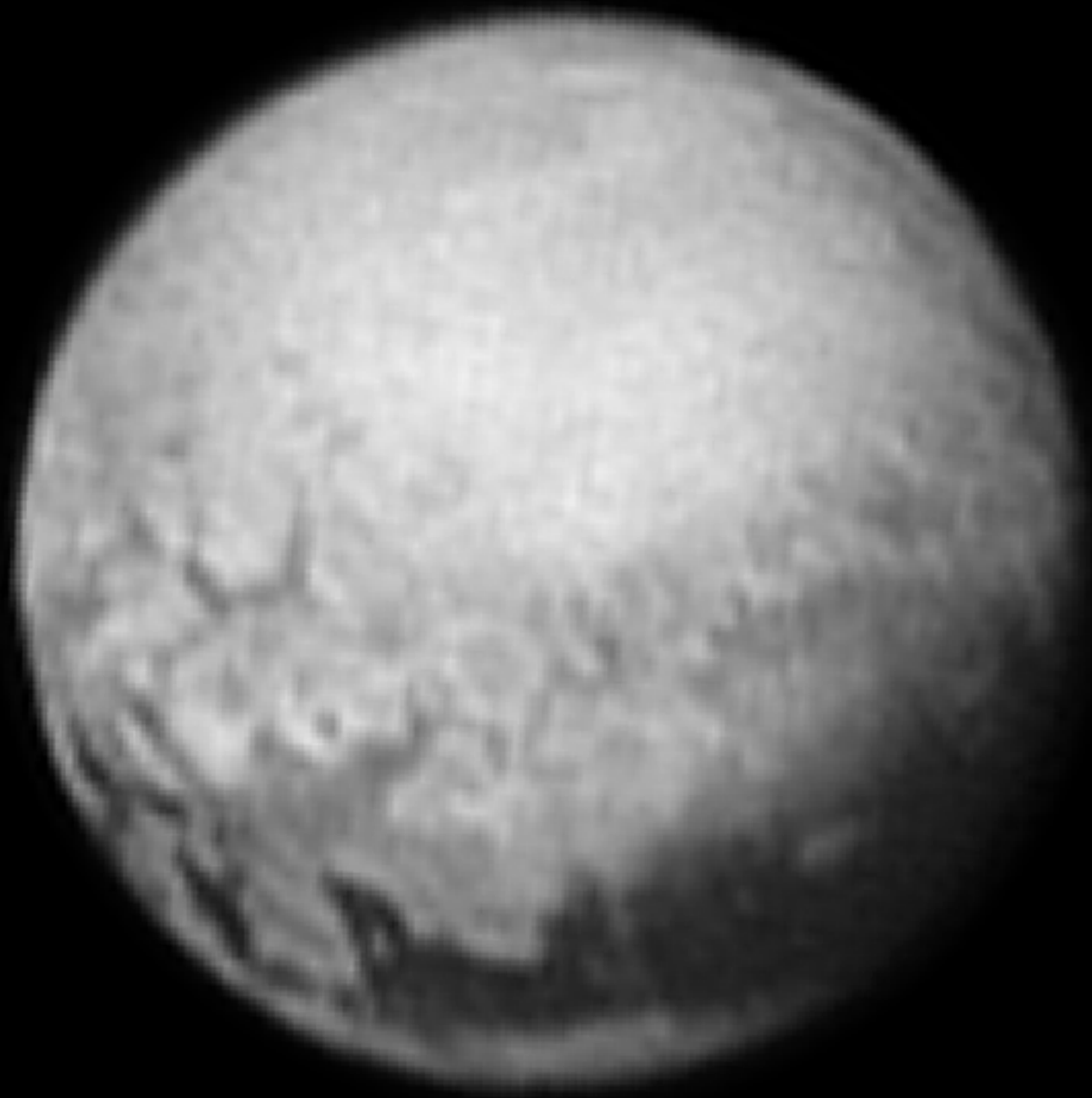
With just hours to spare, Alice Bowman and the mission engineers:

- Found the spacecraft and woke it up.
- Figured out what caused it to disappear.
- Rewrote system software to avoid the problem.
- Tested new software on the ground.
- Reprogrammed spacecraft computer 6 billion km away.

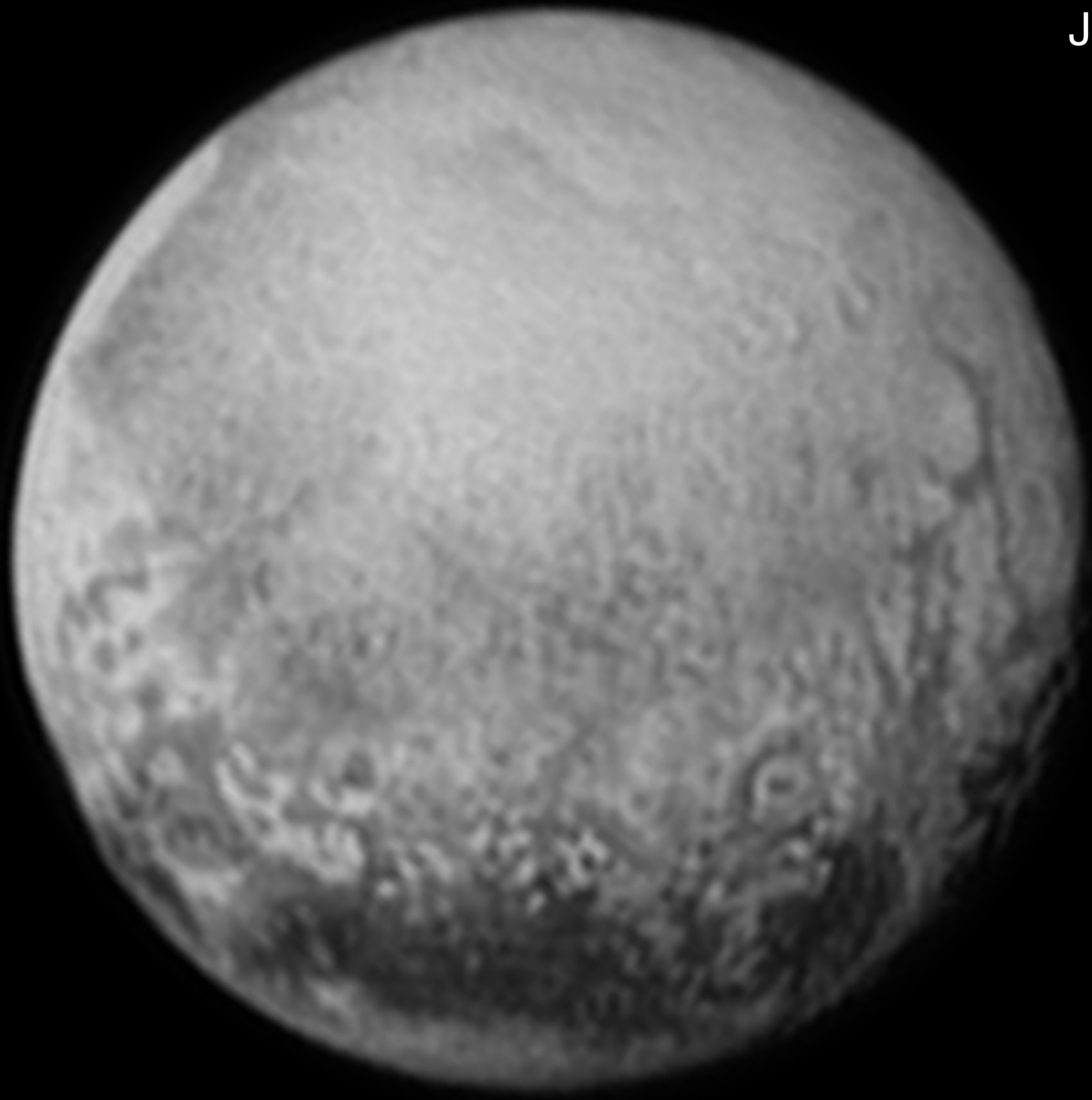
Two days later we were back on track.

July 8, 2015

July 9, 2015



July 12, 2015



Events of Pluto Flyby Day, July 14 2015

- 3 AM: Earth to receive highest-resolution global image
- 7:50 AM: Closest Approach to Pluto
- All Day: Spacecraft is observing and not supposed to communicate with us
- 8 PM: Earth to receive ‘Phone Home’ signal from spacecraft

July 14 2015, 6:05 AM

The ‘Heart’ on Pluto.
True color.

July 13, 2015


EXIT


last side for

The rest of the day, New Horizons is observing Pluto, while we are waiting anxiously to hear from it…


NEW HORIZONS
Flight Control (FC)
Flight Control (FC)


GUEST


NASA - JHUAPL

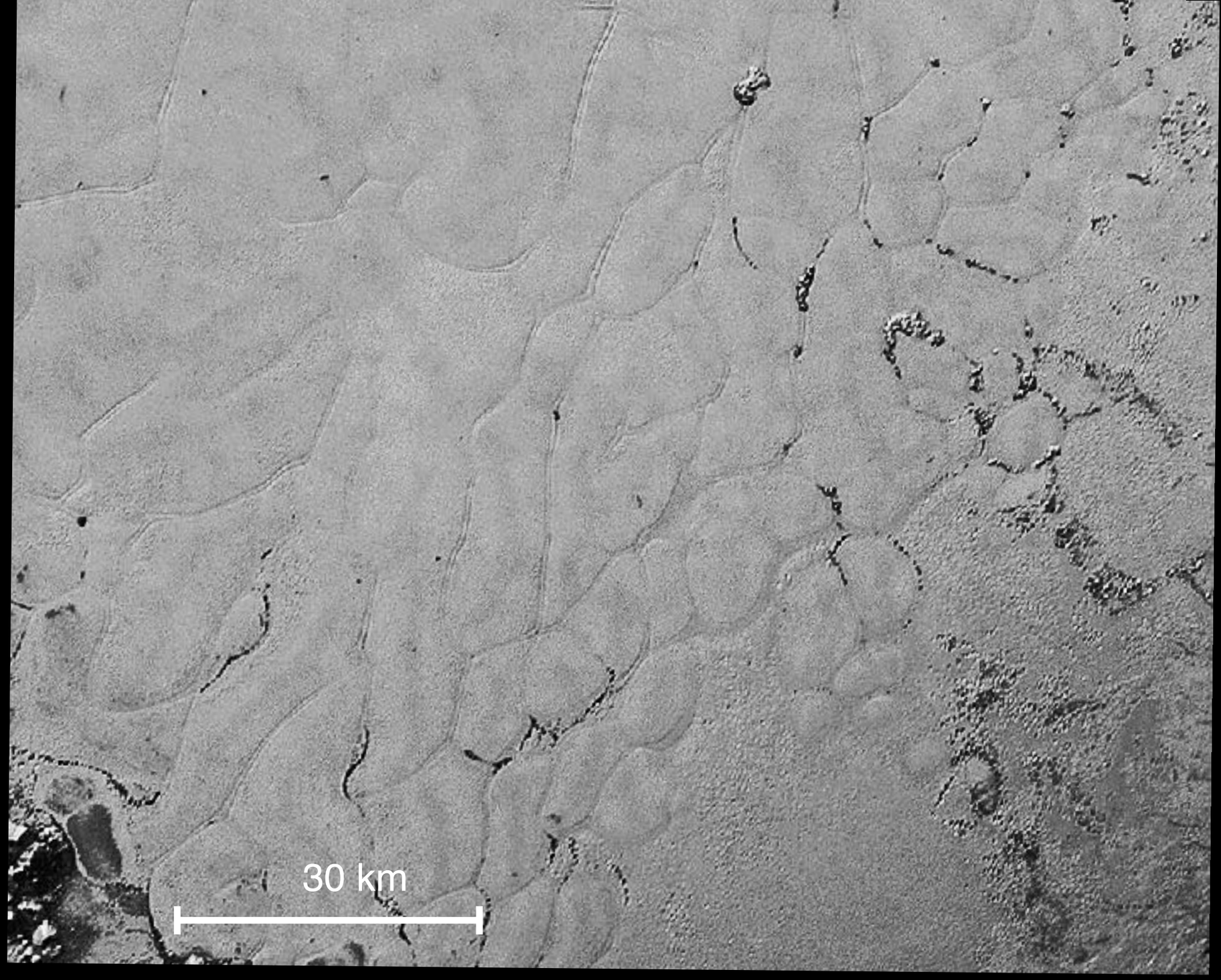
After 9.5 years and 6 billion km, we arrived… one minute early!

July 13, 2015

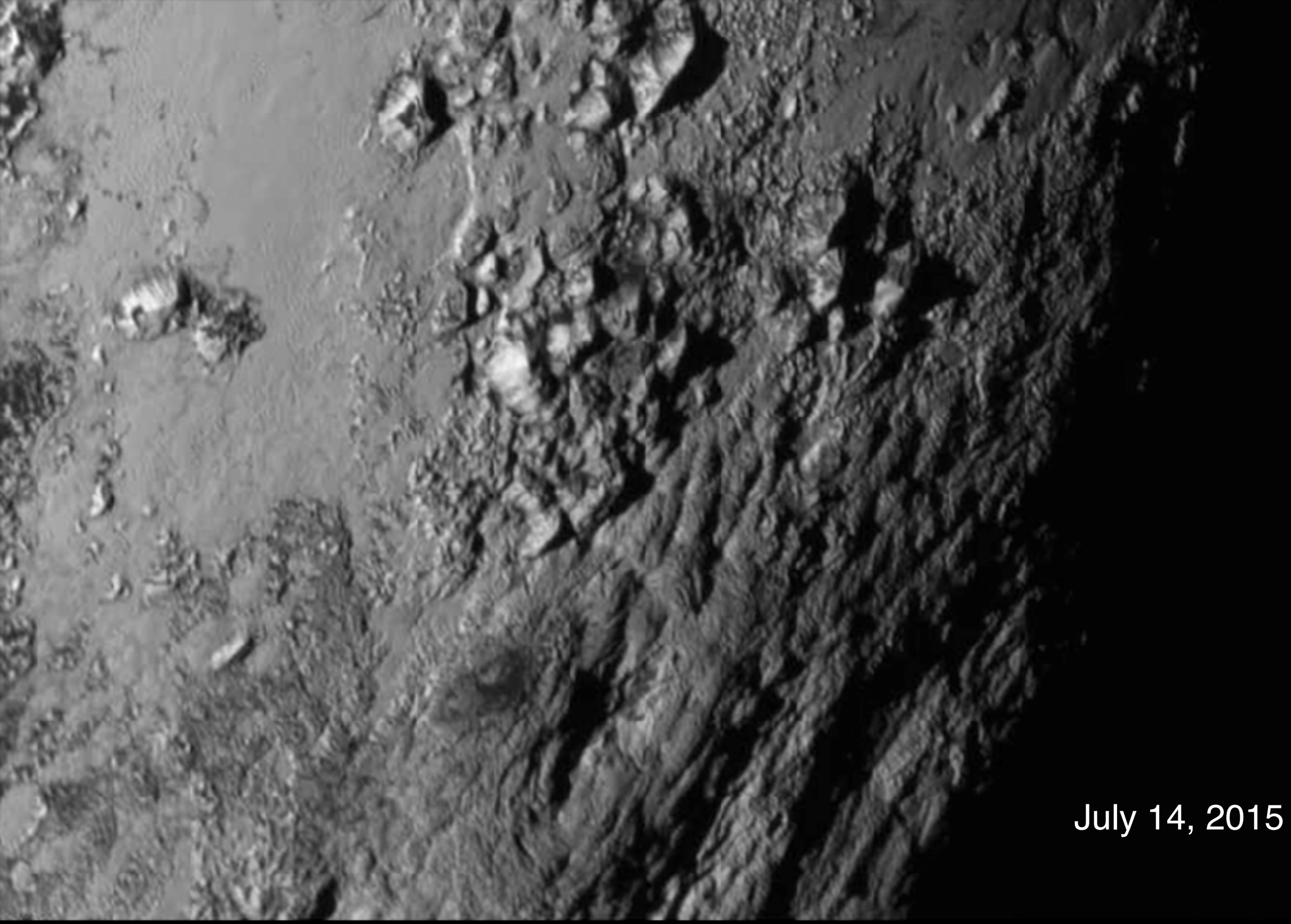
Pluto, true color, stretched

Different colors mean different regions:
White: Pure nitrogen ice
Red: Organic molecules
Yellow, Blue, Green: CH_4, H_2O, other ices

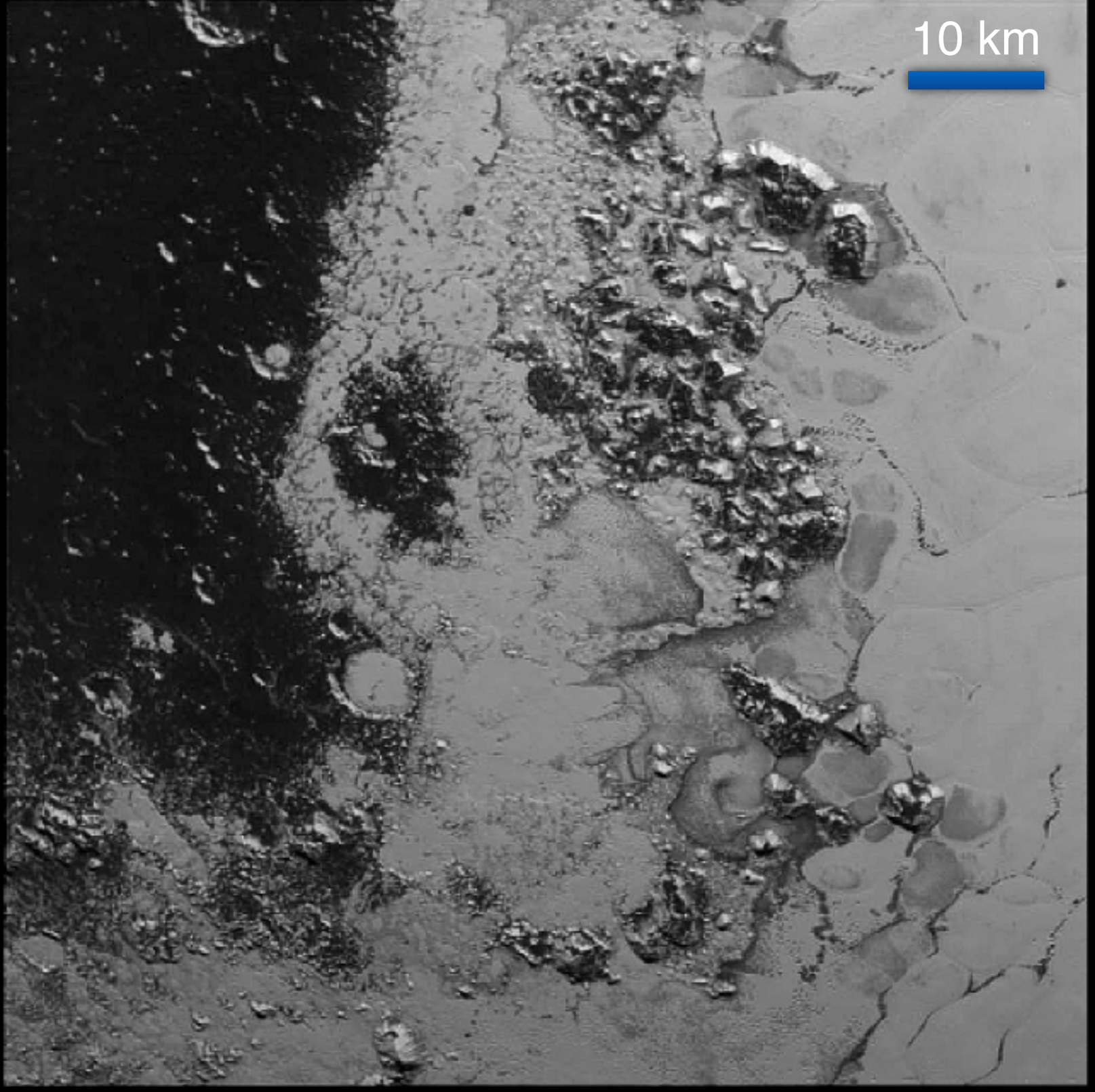
July 14, 2015



Pluto’s ice flows, close-up
Nitrogen ice is flowing, creeping, and moving across the surface like a glacier.
Other ices may float on top, like mountains or sailboats.
Nitrogen cells are caused by thermal convection — like a rolling boil of chai, but billions of times slower.



Ice Mountains on Pluto, 4,000 meters high. And a huge hole.



July 14, 2015

Steep mountains of water ice poke through the nitrogen ice.

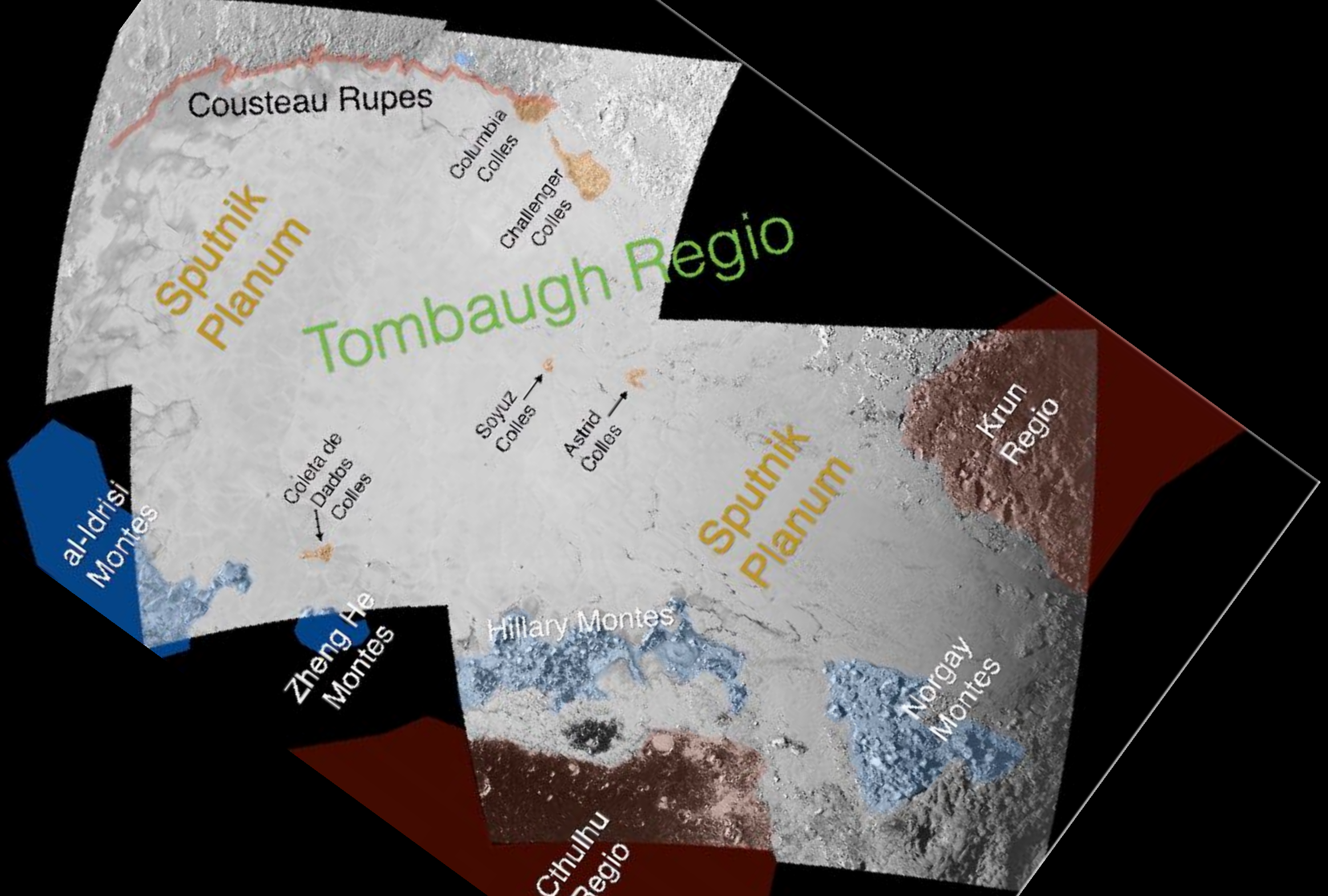
A few impact craters, but not many! So it is a new, fresh surface.

Charon in color, revealing transport of volatiles, a ‘mountain in a moat,’ and a bizarre cracked surface. Caused by thermal contraction as Pluto cools?

July 14, 2015

Charon and the Small Moons of Pluto

The small moons' rotations are fast - not in synchronous rotation and not well explained.



We are making new maps of Pluto and Charon, using suggestions from people, mythologies, and explorers all around the world.

Current map is only temporary names — not official.

Long shadows
and atmospheric layers
as we are leaving Pluto…

Hillary Montes
1.7 km high

Norgay Montes
3.4 km high - tallest on Pluto

Henry's Predictions for Pluto, c. 2012

Pluto will have:

- Because Pluto is small and far from the Sun, it will be cold.
- The cold surface and interior means no liquids, no oceans, no plate tectonics, no volcanoes... nothing young. Everything will be OLD!
- The thin atmosphere means no rivers, no oceans, no wind, no erosion... OLD!
- Surface will have a lot of impact craters, and not much else.

Pluto's surface is very YOUNG. We are baffled...
and all of my guesses were completely wrong!

What We Found on Pluto

- Pluto has a ‘young’ (~10 Myr), active surface
- Somehow Pluto is ‘warm’ inside, and driving convection.
- Mountains are forming right now. Ice is flowing. Glaciers are active.
- There is a lot of diverse chemistry on the surface: hydrocarbons, tholins, organics

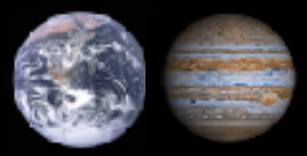
- Pluto is an active and awesome place.
  - From any standpoint — geological processes, surface chemistry, atmospheric interactions, diversity — Pluto is clearly a planet.

NB: Although Pluto has water and organic molecules, it is not a good candidate for life — look somewhere warmer!

New Horizons Mission Timeline

Mission Idea

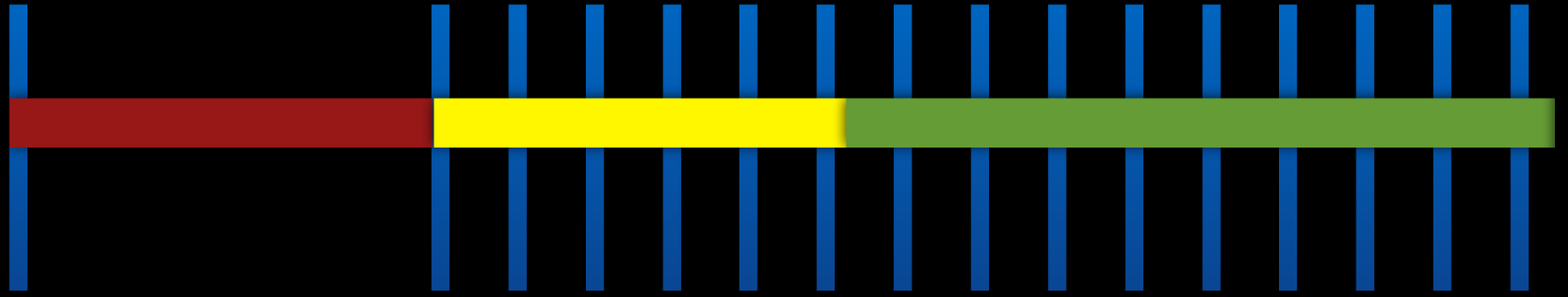
Mission selected by NASA



Launch

Jupiter Flyby

Pluto Flyby!



New Horizons Extended Mission to the Kuiper Belt!

- Distant flybys of ~20 KBOs, through 2018
- Close flyby of KBO, 45 km diameter. January 1, 2019
  - Same flyby distance as Pluto, but 20x smaller object

And then…

Batteries and fuel depleted: 2040?

- 2100: Leave Kuiper belt
- 50,000 AD: Leave solar system
- 500,000 AD: Distant flyby of nearby stellar system


MAKE

Stayed tuned through 2020's as we fly through the Kuiper belt.

pluto.jhuapl.edu or nasa.gov/newhorizons

throop@psi.edu

Question:

WHAT IS A PLANET?

Greek definition of
Planet (πλανητ):

~~"WANDERING STAR"~~

planet ('plænɪt), *n.*[1] Forms: 3-6 **planete**, (4-6 **-ette**, 5 **-ett**, *Sc.* **-ait**, 6 *Sc.* **-eit**, 7 **plannet(t)**, 5- **planet**.

[ME. a. OF. *planete* (F. *planète*), ad. late L. *planēta* or *planētēs* (cited only in pl. *planētæ* = cl. L. *stellæ errantes*), a. Gr. πλανήτης wanderer, hence, in *pl.* (ἀστέρες) πλανῆται wandering stars, planets, f. πλανᾶν to lead astray, in *pass.* to wander. (Another Gr. form was πλάνης, -ητος, in pl. πλάνητες ἀστέρες, L. *planētes*.)]

† **1. a.** *Old Astron.* A heavenly body distinguished from the fixed stars by having an apparent motion of its own among them; each planet, according to the Ptolemaic system, being carried round the earth by the rotation of the particular sphere or orb in which it was placed. *Obs*.

The seven planets, in the order of their accepted distance from the Earth, were the Moon, Mercury, Venus, the Sun, Mars, Jupiter, and Saturn.

[**c1050** *Byrhtferth's Handboc* in *Anglia* (1885) VIII. 320 þa steorran þe man hæt planete on lyden.]

a1300 *Cursor M.* 1550 (Cott.) þe planetes all ar went again O þair first making in to þe state.

c1400 *Destr. Troy* 4366 Venus the worthy..of planettes of prise has hor pure nome.

c1420 LYDG. *Assembly of Gods* 1695 The seuyn planettys Haue her propre names by astronomers.

c1470 HENRY *Wallace* xi. 500 Quhill day began to peyr; A thyk myst fell, the planet was not cleyr.

1481 CAXTON *Myrr.* i. xx. 60. A way that is comune to the vii planetes.

1600 NASHE *Summer's Last Will* D j. Resplendent Sol, chiefe planet of the heauens.

1621 BURTON *Anat. Mel.* i. ii. i. ii. (1651) 45 Gregorius Tholosanus makes seven kindes of ætherial spirits or angels, according to the number of the seven Planets, Saturnine, Jovial, Martial.

1687 tr. *Marana's Turkish Spy* i. xii. 35 It is a great while since we have had any Commerce here with the Sun; there being forty nine Days since this beauteous Planet appeared to us.

1727 BAILEY vol. II. s.v., There is none of the Planets, except the Sun that shines with his own Light.

1766 PORNY *Heraldry* (1787) 19 Arms..are blazoned..by Planets, when they belong to Sovereign Princes, Kings, and Emperors.

Historically, 'Planet' has referred to moons, stars, asteroids, and even the Sun.

Is Pluto a Planet?

Yes !!!

- It orbits the Sun
- It is big enough so that its own gravity makes it into a round ball
- It has five moons
- It has an atmosphere
- We've always called it a planet

No !!!

- It's smaller than the other planets
- Its orbit is egg-shaped and tilted
- It's just like the other 500 Kuiper Belt objects, and we don't call them planets
- If it was discovered today, we would not call it a planet

IAU Definition of Planet (2006)

"The IAU therefore resolves that "planets" and other bodies in our Solar System, except satellites, be defined into three distinct categories in the following way:

(1) A "planet" is a celestial body that (a) is in orbit around the Sun, (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, and (c) has cleared the neighborhood around its orbit.

(2) A "dwarf planet" is a celestial body that (a) is in orbit around the Sun, (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, (c) has not cleared the neighbourhood around its orbit, and (d) is not a satellite.

(3) All other objects except satellites orbiting the Sun shall be referred to collectively as "Small Solar-System Bodies".

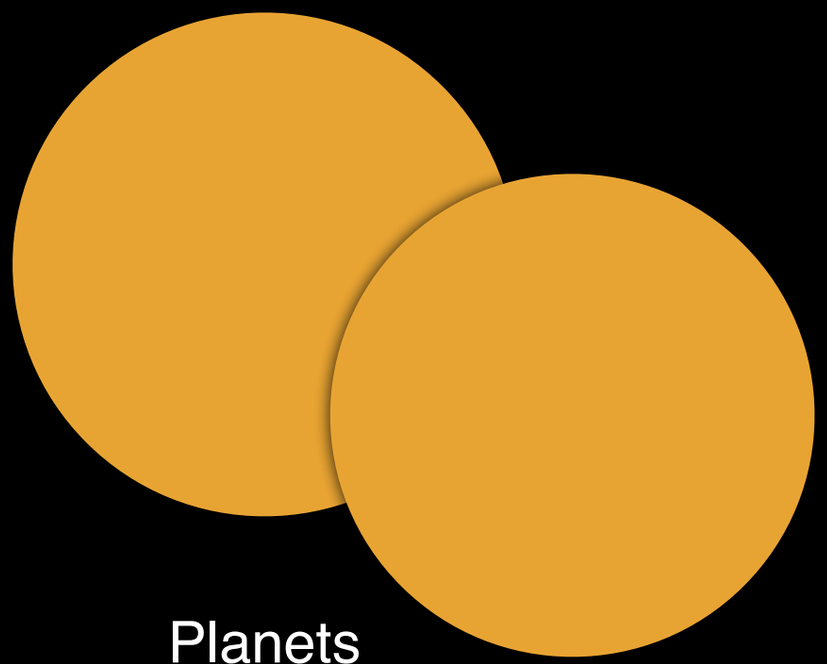
Problem I: The 800+ extrasolar planets aren't 'planets'?

Problem II: But Jupiter isn't 'rigid'!

Problem III: Saturn isn't round!

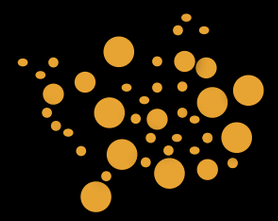
Problem IV: Earth, Jupiter, Moon, etc have not 'cleared their neighborhood'!

How Big is a Planet?



Planets
10,000 km

Pluto
100 - 1000 km



Dust Particles and Rocks
1 mm - 1 meter

What is the difference between a mountain and a hill? It can be a fine line...

August 2006: International Astronomical Union, Prague

This group voted to call Pluto a ‘Dwarf Planet.’
But not everyone agrees, and this is how science works.

Most scientists still call Pluto a planet, and you can too.